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Genesis of the « System & Contrast » model originates from a series of collaborations between the author and the METISS/PANAMA research team at the D5 department of IRISA in Rennes, France, in the context of the QUAERO project. It is consecutive to the definition of the « semiotic structure » as provided by the same team. The methodology leading to the determination of the semiotic structure aims at representing the high-level organization of music pieces in a concise, generic and reproducible way as a low-rate stream of arbitrary symbols from a limited alphabet, which results into a sequence of « semiotic units ». The purpose of the System & Contrast model is to address the internal organization of the semiotic units.

The System & Contrast model is shown to proceed from concepts that belong to varied disciplines. In the field of cognitive psychology, the model can be considered in relation to the three « levels of musical experience » introduced by Bob Snyder. In Bob Snyder's view, each level is associated to a particular set of time scales. The System & Contrast model relates to Snyder's level of « melodic and rhythmic grouping ». In the field of music analysis, the System & Contrast model is related to William E. Caplin's approach to the traditional Formenlehre, the « teaching of form », a sub-discipline of music theory that largely focuses on the forms found in music from the classical Viennese period. Still in the field of music analysis, a number of similarities can be found between the System & Contrast model and Eugene Narmour's views on musical expectation, more particularly the fundamental hypotheses underlying Narmour's « implication-realization » model of musical expectation, along with his considerations on « rule-mapping ». In the field of information theory, the System & Contrast model is underlain by modern mathematical interpretations of Ockham's « razor » principle, leading to the « model selection » problem and its generic solution drawn from Jorma Rissanen's « Minimum Description Length » concept. Resolution of the model selection problem will be shown to provide key methodological guidelines in the process of music description using the System & Contrast model.

We define as « studio-based popular music » a trend of so-called « popular music » in the context of which the recording medium is used for its unique creative potentials, with the studio being used as a musical instrument. This trend can be considered as starting around the mid 1960's, most notably with the beginning of the Beatles' recording career. Music description using the System & Contrast model is mainly performed on « studio-based popular music » pieces, as well as on music from the classical Viennese period.

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Methodological and musicological investigation of the System & Contrast model for musical form description.

La genèse du modèle « Système & Contraste » résulte d'une série de collaborations entre l'auteur et l'équipe de recherche METISS/PANAMA de l'IRISA dans le cadre du projet QUAERO. La définition du modèle « Système & Contraste » est consécutive à celle de la « structure sémiotique », premier résultat de ces collaborations. L'objet de la structure sémiotique est la représentation d'une pièce musicale en tant que séquence de faible débit de symboles arbitraires issus d'un alphabet limité, les « unités sémiotiques ». L'objet du modèle Système & Contraste consiste en la description interne des unités sémiotiques.

Le but premier de la présente étude est de consolider le contexte du modèle, en montrant les liens qu'il peut avoir avec plusieurs disciplines. L'établissement de tels liens permet d'expliquer et de développer dans le même temps un certain nombre d'aspects spécifiques au modèle. À cette fin, les travaux présentés dans ce mémoire éclairent les liens entre le modèle S&C avec différentes disciplines, étayent ses fondements sur des concepts issus de la théorie de l'information et montrent son efficacité sur plusieurs études de cas détaillées portant sur divers genres musicaux.

Dans le domaine de la psychologie cognitive, le modèle peut être considéré en relation avec les trois « niveaux d'expérience musicale » introduits par Bob Snyder. Selon Snyder, chacun des niveaux est associé à un ensemble particulier d'échelles de temps. Le modèle Système & Contraste peut s'appliquer à l'échelle dite de « groupement mélodique et rythmique ». Dans le domaine de l'analyse musicale, le modèle est compatible avec l'approche défendue par William E. Caplin concernant le Formenlehre (littéralement, « apprentissage de la forme »), une discipline traditionnellement centrée sur les formes rencontrées dans la musique de la période classique Viennoise.

Toujours dans le domaine de l'analyse musicale, de nombreux liens existent entre le modèle Système & Contraste et les principes d'Eugene Narmour concernant le phénomène d'« attente » en musique (« musical expectation »), plus particulièrement avec les hypothèses fondamentales qui sous-tendent le modèle d'« implication-réalisation », ainsi qu'avec le principe de « rule-mapping » (qu'on pourrait traduire par « mise en cohérence de règles »).

Dans le domaine de la théorie de l'information, le modèle Système & Contraste est sous-tendu par certaines interprétations du principe dit du « rasoir d'Ockham », interprétations qui conduisent au problème dit de « model selection » (« sélection de modèles »), dont la solution générique est déduite du principe dit de la « Minimum Description Length » (« longueur de description minimale ») introduite par Jorma Rissanen. Cette résolution du problème de model selection fournira des indications d'ordre méthodologiques qui s'avèreront essentielles dans le procédé de description basé sur le modèle « Système & Contraste ».

Nous définissons comme genre musical au sens large la « studio-based popular music » (« musique populaire basée sur les pratiques du studio »), dans lequel le support d'enregistrement est utilisé pour ses potentiels créatifs spécifiques. La naissance d'un tel genre peut être placée vers le milieu des années 60. Dans le cadre du présent travail, le modèle « Système & Contraste » est largement utilisé pour la description de pièces issues d'un tel genre, tout en s'avérant compatible avec la musique appartenant à la période classique Viennoise. En particulier, il comprend cinq études de cas utilisant les particularités du modèle Système & Contraste pour mettre à jour certaines propriétés spécifiques aux morceaux considérés.

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FOREWORD

The main focus for the present research report is the « System & Contrast » model for musical form description. Genesis of this model originates from a series of collaborations between the author and the METISS/PANAMA research team at INRIA[1], in the context of the QUAERO project[2], with Frédéric Bimbot as principal investigator.

The report is meant to be understood as a continuation to the previous works about musical structure conducted by the METISS/PANAMA team[3]. While the methodology leading to the determination of the semiotic structure aims at « representing the high-level organization of music pieces in a concise, generic and reproducible way […] as a low-rate stream of arbitrary symbols from a limited alphabet »[4], resulting into a sequence of « semiotic units » or « segments » at a particular time scale, our goal with the present document is to provide further insights into the description of the semiotic unit's internal organization[5].

The report is a slightly modified version of a Master Thesis achieved as a partial requirement for the Master's degree in Musicology at the Université Catholique de Louvain[6], under the supervision of Brigitte Van Wymeersch.

1 See INRIA, « Panama, Présentation », https://team.inria.fr/panama/ (accessed on July 10th, 2013).
2 See QUAERO, « Quaero en bref », http://www.quaero.org/quaero-en-bref/ (accessed on July 10th, 2013).
3 Frédéric BIMBOT, Olivier Le BLOUCH, Gabriel SARGENT, Emmanuel VINCENT, « Decomposition Into Autonomous and Comparable Blocks: A Structural Description of Music Pieces », *Proceedings of the 11th International Society for Music Information Retrieval Conference*, 2010, p. 189-194. Frédéric BIMBOT, Emmanuel DERUTY, Gabriel SARGENT and Emmanuel VINCENT, « Methodology and resources for the structural segmentation of music pieces into autonomous and comparable blocks », *Proceedings of the 12th International Society for Music Information Retrieval Conference*, 2011, p. 287-292. Frédéric BIMBOT, Emmanuel DERUTY, Gabriel SARGENT and Emmanuel VINCENT, « Semiotic structure labeling of music pieces: concepts, methods and annotation conventions », *Proceedings of the 13th International Society for Music Information Retrieval Conference*, 2012, p. 235-240. Gabriel SARGENT, Frédéric BIMBOT and Emmanuel VINCENT, « A Regularity-Constrained Viterbi Algorithm And Its Application To The Structural Segmentation Of Songs », *Proceedings of the 13th International Society for Music Information Retrieval Conference*, 2012, p. 483-488.
4 Frédéric BIMBOT & al., *op. cit.*, 2012, p. 235.
5 Frédéric BIMBOT, Emmanuel DERUTY, Gabriel SARGENT, Emmanuel VINCENT, « System & Contrast : a Polymorphous Model of the Inner Organization of Structural Segments within Music Pieces (Original Extensive Version) ». *IRISA Internal Report n° PI-1999, 2012, hal-00868398, version 1.*
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INTRODUCTION

Study of the musical structure primarily pertains to the field of music analysis, « that part of the study of music that takes as its starting-point the music itself, rather than external factors »[7]. Music analysis is a complex and composite field that possesses links with criticism (be it descriptive or judicial) and music history. The present work is underlain by a vision of music analysis in which criticism and music history are voluntarily left out[8]. Neither is it concerned by considerations that relate to the composition method or the perception of the music[9]. In that sense, our study of the musical structure can be considered as purely descriptive.

Use of the term « description » can be observed in the field of Music Information Retrieval or M.I.R. for short[10], in which particular features are automatically extracted from the audio signal corresponding to the music, often in the form of « descriptors ». Results of such an extraction may or may not correspond to humanly understandable musical characteristics[11]. This is an approach that aims at objectivity. For a given music piece of section, the value of a particular descriptor is unique. In other words, given the same music piece and given the same descriptor, the value is always identical.

M.I.R. experiments may aim at extracting or describing a traditional musical feature such as the tempo, the lead vocal melodic content or the tonality. This may be possible using particular descriptors or combination of descriptors. In this case, the experiment may include a manual annotation phase, during which these characteristics are written down manually by human annotators, which defines a « ground truth ». Automatic output is compared with ground truth, and the closer the output to the ground truth, the more successful the experiment[12].

This raises the important question of the « uniqueness » of the musical feature. For instance, let's consider the tempo. In the case of the music piece being written on a score[13], the tempo can indeed be considered as unique. The « true » tempo is written on the score. In the case of certain « pop » music pieces, for which there is no score, the tempo may be difficult to define and annotate properly[14]. In this regard, it is impossible to properly evaluate the success of a M.I.R. experiment that aims at finding tempos from a corpus of « pop » music pieces. One may want to redefine the goal of the experiment, and, for a start, redefine the notion of ground truth in this case.
One of the potential goals of M.I.R. is to extract or describe the « structure » of a music piece[15]. As a consequence, ground truth has to be defined accordingly. In other words, we want to be able to define structure in a generic and reproducible way. If ground truth is badly defined, M.I.R. experiments concerning structure will have less meaning[16]. Contributing to the definition of musical structure as ground truth is one of the goals underlying

7 Ian D. BENT and Anthony POPLE, « Analysis », *Grove Music Online*, Oxford Music Online, Oxford University Press, http://www.oxfordmusiconline.com/subscriber/article/grove/music/41862 (accessed on July 8th, 2013). The same source also states that « more formally, analysis may be said to include the interpretation of structures in music, together with their resolution into relatively simpler constituent elements, and the investigation of the relevant functions of those elements ». Unfortunately, no definition is provided for the word « structure » in this context, which makes this particular sentence difficult to interpret.

8 This is not the case for many important music analysis works. In Charles ROSEN, *The Classical Style*, Norton, 2nd edition, 1997, the author routinely interlaces description with judicial criticism, using terms such as « beautifully handled » or « delightful » (p. 66), or even meddles music analysis, music history and judicial criticism, perfunctorily condemning an entire music style, the « galant » mode, on the ground that it would be « insipid » (p. 112).

9 This makes our approach compatible with the « neutral level of analysis » as suggested by Jean-Jacques NATTIEZ, *Musicologie Générale et Sémiologie*, Christian Bourgeois, 1987.

10 « Sound and music description » is for instance the title of a research area of the Music and Technology Group at the Pompeu Fabra University in Barcelona. This is a team that's very active in the M.I.R. community. See UNIVERSITAT POMPEU FABRA, « Sound and music description », Research Areas, Music and Technology Group, http://mtg.upf.edu/research/areas/musicdescription (accessed on September 5th, 2013).

11 The spectral centroid, for instance, possesses a clear perceptual counterpart. A high spectral centroid will often correspond to a clear-sounding sample. The same cannot be said of the fourth MFCC coefficient.

12 This describes in a nutshell the MIREX contest, see MIREX, « Mirex Home », http://www.music-ir.org/mirex/wiki/ MIREX_HOME (retrieved on September 4th, 2013).

13 Most western classical music pieces are written on a score before they are recorded.

14 Many « pop » songs are recorded before they are actually written. See *'Listen to My Voice': The Evocative Power of Vocal Staging in Recorded Rock Music and Other Forms of Vocal Expression*, submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy at the University of Liverpool, p. 8. It may be sometimes difficult to define whereas, for instance, the tempo is 60 or 120 bpm.

15 See for instance MIREX, « 2012:Structural Segmentation », MIREX 2012 Possible Evaluation Tasks, 2012:MIREX Home, http://www.music-ir.org/mirex/wiki/2012:Structural_Segmentation (retrieved on September 5th, 2013).

16 This concern is shared for instance by Geoffroy PEETERS and Karën FORT, « Towards A (Better) Definition Of The Description Of Annotated MIR Corpora », *Proceedings of the 13th International Society for Music Information Retrieval Conference*, 2012, p. 25-30.

this work.

Before actually defining « structure » in a generic and reproducible way, i.e. structure that can be used as ground truth, one should define « structure » in any situation. In the field of musicology, structure is a notion that appears to constitute an open problem. For instance, the New Grove Dictionary of Music and Musicians, a standard reference for musicologists, doesn't provide a standardized definition. Examination of articles containing the term yields a number of varied results. In a number of cases, structure appears to concern large-scale objects[17]. In some other cases, structure describes the organization of smaller-scale objects[18].

In the field of musical analysis, use of the term « structure » depends on the author. For instance, the « grouping structure » is central to the Generative Theory of Tonal Music. Such a structure is formed when a person « is confronted with a series of elements or a sequence of events ». In this case, « the person spontaneously segments or "chunks" the elements or events into groups of some kind [...] This grouping can be viewed as the most basic component of musical understanding »[19]. The resulting grouping structure can be represented as a hierarchical tree.

In Schenkerian analysis, a fundamental notion to the theory, the *Ursatz*, may be understood, generally speaking and independently from Schenker's successive developments, as a simplification of the musical content, a design that underlies the musical structure of a piece, i.e. a fundamental structure[20]. Additionally, it has to be noted that a number of authors make use of the word « structure » without providing a definition for it[21].

17 A part of the study of Javanese and Balinese music, the « colotomic » structure refers to « major » sections that begin and end with a gong beat. See GROVE MUSIC ONLINE, « Analysis », *Grove Music Online*, Oxford Music Online, Oxford University Press, http://www.oxfordmusiconline.com/subscriber/article/grove/music/06155 (accessed on September 4th, 2013). A study of arrangement in jazz provides a number of examples of « structure » and « structural divisions », which last anywhere between 2 and 20 bars. In this case, the discovery method for the structural divisions is not specified. See Gunther SCHULLER, « Arrangement », *Grove Music Online*, Oxford Music Online, Oxford University Press, http://www.oxfordmusiconline.com/subscriber/article/grove/music/J015900#F930001 (accessed on September 4th, 2013). At least at first glance, the particular time scale of structural objects appears to be compatible with which of pop-music « verses » or « choruses ».

18 This appear to concern structures that are specific to particular aspects of the music, such as a « melodic structure » of Hutu music in Peter COOKE and Jos GANSEMANS, « Rwanda and Burundi », *Grove Music Online*, Oxford Music Online, Oxford University Press, http://www.oxfordmusiconline.com/subscriber/article/grove/music/42125#F005887 (accessed on September 4th, 2013), or a « harmonic structure » in jazz music, see Barry KERNFELD, « Blues Progression », *Grove Music Online*, Oxford Music Online, Oxford University Press, http://www.oxfordmusiconline.com/ subscriber/ article/grove/music/J049100#F930024 (accessed on September 4th, 2013).

19 Fred LERDAHL and Ray JACKENDOFF, *A Generative Theory of Tonal Music*, M.I.T. Press, 1983, p. 13.

20 William DRABKIN, « Ursatz », *Grove Music Online*, Oxford Music Online, Oxford University Press, http://www.oxfordmusiconline.com/ subscriber/article/grove/music/28844 (accessed on September 4th, 2013).

21 See Charles ROSEN, *op. cit.*, 1997, p. 99-108. Part II of the book is entitled « Structure and ornaments ». The meaning of the term appears to be evident to the author, since he doesn't bother to specify its meaning.

In the field of M.I.R., a small number of projects explore the notion of « structure ». Typically, such projects include a corpus of human-made annotations[22]. A study of three such annotation corpora shows that they result in objects of varied scales. Previous theoretical definition for the notion of « structure » is often not published. We may conclude that in such cases, the annotators may be left at best with guidelines, at worst with only their intuition. During the course of the project conducted by the METISS/PANAMA team, which concern the so-called « semiotic structure », one of the goal was to provide both theoretical background and methodological guidelines[23].

As detailed during **Chapter 1** of the present document, another goal of this project consisted in specifying particular time scales on which a particular structure can be witnessed. This provides answers to the aforementioned concern according to which mentions and definitions for « structure » in the literature can often be seen in relation to considerably different time scales. As quoted from the **Foreword,** while the methodology leading to the determination of the semiotic structure aims at « representing the high-level organization of music pieces in a concise, generic and reproducible way […] as a low-rate stream of arbitrary symbols from a limited alphabet »[24], resulting into a sequence of « semiotic units » or « segments » at a particular time scale, our goal with the present document is to provide a contribution to the description of the semiotic unit's internal organization.

Description of the semiotic unit's internal organization is primarily based on the System & Contrast model, which is the primary focus of the present document. At the time of writing, this model has been previously introduced in one published paper[25], as well as further described in a project of journal article, which focus largely lies on technical and conceptual aspects of the model[26]. In parallel to developments of the model in the context of Engineering Sciences, it was felt as a very relevant goal to complementarily investigate on the musicological properties of the model, which is the goal of the current document.

The initial purpose of the System & Contrast model, or S&C model for short, is the description of the internal organization of the semiotic units[27]. As such, it applies to the description of « mid-level » music form[28], in the context of varied music styles, be it « classical » western music or otherwise. Accordingly, it is designed to be made as independent from particular « musical dimensions » as can possibly be.

22 Amongst them, the S.A.L.A.M.I. project at Mc Gill University, described as a « computational musicology project ». See Mert BAY, John Ashley BURGOYNE, Tim CRAWFORD, David De ROURE, J. Stephen DOWNIE, Andreas EHMANN, Benjamin FIELDS, Ichiro FUJINAGA, Kevin PAGE, and Jordan B. L. SMITH, Structural Analysis of Large Amounts of Music Information, http://www.diggingintodata.org/LinkClick.aspx?fileticket=tTEM9t3kcY8%3d&tabid=179 (accessed on September 4th, 2013). The part of the QUAERO project at IRCAM concerning musical structure, see Geoffroy PEETERS and Emmanuel DERUTY, « Is Music Structure Annotation Multi-dimensional? A Proposal for Robust Local Music Annotation », Learning the Semantics of Audio Signals workshop, Graz, Austria 2009. Geoffroy PEETERS and Emmanuel DERUTY, « Toward Music Structure Annotation », *Proceedings of the 10th International Society for Music Information Retrieval Conference*, *Late breaking news,* 2009. The part of the QUAERO project at INRIA concerning musical structure, see Frédéric BIMBOT & al., *op. cit.*, 2010, Frédéric BIMBOT & al., *op. cit.*, 2011, Frédéric BIMBOT & al., *op. cit.*, 2012.

23 For the theoretical background, see Frédéric BIMBOT & al., *op. cit.*, 2010 and Frédéric BIMBOT & al., *op. cit.*, 2011. For the methodological guidelines, see Frédéric BIMBOT & al., *op. cit.*, 2012.

24 Frédéric BIMBOT & al., *op. cit.*, 2012, p. 235.

25 Frédéric BIMBOT & al., *op. cit.*, 2012, p. 237-238. More details are provided in the addendum Frédéric BIMBOT, Emmanuel DERUTY, Gabriel SARGENT and Emmanuel VINCENT, « Complementary report to the Article “Semiotic structure labeling of music pieces: concepts, methods and annotation conventions” (Proceedings ISMIR 2012) », http://hal.archives-ouvertes.fr/docs/00/71/31/96/PDF/PI_1996_-_System_Contrast_as_technical_report_.pdf (accessed on July 1st, 2013).

26 Frédéric BIMBOT, Emmanuel DERUTY, Gabriel SARGENT and Emmanuel VINCENT, « System & Contrast: A Polymorphous Model Of The Inner Organization Of Structural Segments Within Music Pieces », project for a journal article currently in progress, available on demand from any of the co-authors.

27 In Frédéric BIMBOT & al., *op. cit.*, 2012, p. 237-238, the use of the S&C model is referred to as the « morphological analysis » of the semiotic unit. It goes together with the « syntagmatic » and « paradigmatic » analyses. The combination of the three analyses results into the identification of the semiotic units.

28 According to Frédéric BIMBOT & al., *op. cit.*, 2011, p. 287, the mid-level is based on elements whose length lies between 1 and 16 seconds.

The S&C model is established on two main hypotheses. According to the first hypothesis, all or part of the content of a semiotic unit can be described as a system of relations between smaller elements, referred to as « morphological units »[29]. According to the second hypothesis, the said relations are based on the notion of « implication », in a sense that relates to Eugene Narmour's interpretation of musical expectation[30].

The model proceeds from concepts that belong to various disciplines. Provided by order of appearance in the present document, the concepts can be organized into five distinct groups:

1. In the field of cognitive psychology, the three « levels of musical experience » introduced by Bob Snyder. In Bob Snyder's view, each level is associated to a particular set of time scales. The S&C model relates to Snyder's level of « melodic and rhythmic grouping »[31].

2. In the field of music information retrieval, our previous work about « semiotic structure »[32]. Whereas the study of the semiotic structure intends to provide a step-by-step, replicable method for the description of the high-level organization of music pieces using « semiotic units », the S&C model focuses on the inner organization of these units.

3. In the field of musical analysis, William E. Caplin's approach to the traditional *Formenlehre*, the « teaching of form », a « venerable » subdiscipline of music theory that largely focuses on the forms observed in music from the classical Viennese period[33].

4. Still in the field of musical analysis, Eugene Narmour's models of musical expectation, more particularly the fundamental hypotheses underlying the « implication-realization » model[34], along with Narmour's views on « rule-mapping »[35], which are strongly related to the systemic relations between elements as described by the S&C model.

5. In the field of information theory, modern mathematical interpretations of Ockham's « razor » principle[36], leading to the « model selection » problem and its generic solution drawn from Jorma Rissanen's « Minimum Description Length » principle[37]. Resolution of the model selection problem provides key methodological guidelines in the process of music analysis using the S&C model.

29 Throughout this work, we'll be accepting the epistemological interpretation of the notion of « system », according to which it is « a complex object made from distinct components linked together by a number of relations », or quite similarly as « a regularly interacting or interdependent group of items forming a unified whole ». See respectively Jean LADRIÈRE, « Système, épistémologie », *Encyclopædia Universalis en ligne*, http://www.universalis-edu.com/ encyclopedie/systeme-epistemologie/ (accessed on June 14th, 2013,) and MERRIAM-WEBSTER, « System », *Merriam-Webster*, http://www.merriam-webster.com/dictionary/system (accessed on June 14th, 2013). Ladrière's original text in French is « Un système est un objet complexe, formé de composants distincts reliés entre eux par un certain nombre de relations ».

30 This particular interpretation, including the mention of implication in this particular sense, is introduced in Eugene NARMOUR, *Beyond Schenkerism: the need of alternatives in music analysis*, University of Chicago Press, 1977, p. 137, as cited by Naomi CUMMING, « The analysis and cognition of basic melodic structures by Eugene Narmour », *Music Analysis*, XI/2/3 (1992), p. 355.

31 Bob SNYDER, *Music and Memory*, M.I.T. Press, 2000. See Chapter 1 in particular.

32 Frédéric BIMBOT & al., *op. cit.*, 2010. Frédéric BIMBOT & al., *op. cit.*, 2011. Frédéric BIMBOT & al., *op. cit.*, 2012.

33 William E. CAPLIN, *Classical form*, Oxford University Press, 1998, p. 3. Arnold SCHOENBERG, *Fundamentals of musical Composition*, Faber & Faber, London, 1967.

34 See in particular Eugene NARMOUR, *The analysis and cognition of melodic complexity: the implication-realization model*, Chicago, University of Chicago, 1992. Naomi CUMMING, « The analysis and cognition of basic melodic structures by Eugene Narmour », *Music Analysis*, XI/2-3 (1992), p. 354-374.

35 Eugene NARMOUR, « Music expectation by cognitive rule-mapping », *Music Perception*, XVII/3, 2000, p. 329-398.

36 William of OCKHAM, S*umma totius logicae*, 1323, as cited and interpreted by Peter D. GRÜNWALD, *The Minimum Description Length Principle and Reasoning under Uncertainty*, ILLC Dissertation Series 1998-03, submitted to the Institute of Logic, Language and Computation, in partial fulfillment of the requirements for the degree of Doctor of Philosophy at the University of Amsterdam (Paul Vitányi, supervisor), 1998, p. v.

37 Jorma RISSANEN, « Modeling by Shortest Data Description », *Automatica*, XIV, 1978, p. 445-471.

We intend to provide a joint interpretation for Snyder's « three levels of musical experience », Caplin's forms, and the semiotic unit. This results in a better understanding of the scope of the S&C model in terms of time scales. We then focus on the systemic nature of the S&C model, by putting it in perspective with Narmour's notion of « implication ».

Once both the scope in terms of time-scale and the nature of the model specified, we consider the influence of the Rissanen's « Minimum Description Length » principle on the model, be it from a theoretical or methodological point of view. A number of musical examples produced throughout the document illustrate the various viewpoints developed in this work.

OUTLINE

The present document is divided into five chapters:

- **Chapter I** provides context by evaluating the respective positions in terms of time scale of Snyder's « levels of musical experience », our own work about semiotic structure, and Caplin's *Formenlehre*.

- **Chapter II** provides context and details by studying the relationships between musical expectation, Narmour's implications, and the S&C model at the pertinent time scale.

- **Chapter III** focuses on the notions of models and description in light of the Minimum Description Length principle, providing additional context and theoretical basis for the S&C model.

- **Chapter IV** takes advantage of the observations made in **Chapter III** to provide refinement perspectives for the S&C model while taking into account potentially conflicting implications.

- **Chapter V** includes case studies showing analysis of recent popular music using the S&C model.

An **Appendix** is also provided, which includes additional details for **Chapter IV**.

CHAPTER I:
TIME SCALES.

In this Chapter, we compare the span of a variety of music-related objects in terms of time scale. As illustrated on **Figure 1**, along our notions of « semiotic units » and « morpho-syntagmatic level »[38], we consider Bob Snyder's memory-based « levels of musical experience »[39], Raymond Monelle's hierarchical tree of musical units[40], as well as Arnold Schoenberg and William E. Caplin's studies on musical form[41].

Snyder.		**Bimbot & al.**		**Monelle, Schoenberg, Caplin.**							
Duration (in seconds).		**Duration (in snaps).**		**Duration (in beats).**	**Monelle.**	**Schoenberg.**			**Caplin.**		
	Form.			Above 32.							
~ 11.5.		~16.	Semiotic segment.	32.	Period.		**Sentence.**	**Period.**		**Sentence.**	**Period.**
	Melodic and rhythmic grouping.	8.	MS level.	16.	Phrase.	Phrase.		Antecedent. Consequent.	Phrase.	Presentation. Continuation.	Antecedent. Consequent.
		4.		8.	Subphrase.		Basic motive. Continuation.			Basic idea. Contrasting idea.	
		2.		4.	Bar.						
		1.		2.	Foot.						
		Less than 1.		1.	Beat.						
				Less than 1.							
~ 0.05.											
	Event fusion.										

Figure 1. Different time scales in music.

38 See in particular Frédéric BIMBOT & al., *op. cit.,* 2011, Section 2.1, as well as Frédéric BIMBOT & al., *op. cit.,* 2012, Section 1.
39 Bob SNYDER, *op. cit.*, 2000.
40 Raymond MONELLE, *Linguistics and Semiotics in Music*. Harwood Academic Publishers, 1992, p. 149-150.
41 Arnold SCHOENBERG, *op. cit.*, 1967. William E. CAPLIN, *op. cit.*, 1998.

Chapter I, Section 1:
Levels of musical experience (Snyder).

Bob Snyder defines three « levels of musical experience », which are illustrated in **Figure 2**[42]. The level of « event fusion » concerns events that cannot be distinguished from each other and are therefore merged together. This results into the approximation of a time limit, above which one can indeed distinguish elements. On **Figure 1**, this limit is written as 0.05s[43]. The level of « melodic and rhythmic grouping » concerns events that are processed and bound together by the listener's brain using perceptual binding. Perceptual binding implies the existence of a number of relations between events, and is limited by the existence of the long-term memory.

Above a particular time scale, the long-term memory acts like a filter that limits the amount of events and relations committed to memory. Their number becomes very small, and the few memorized events and relations become the focus of conscious awareness. The existence of long-term memory therefore results into an upper limit for melodic and rhythmic grouping. On **Figure 1**, this limit is written as 11.5s[44]. Bob Snyder refers to this last level as the level of « form »[45].

Musicians or music analysts seldom count in seconds. They usually prefer to count in beats and bars. Therefore, we have to roughly express the limits between the « melodic and rhythmic grouping » and the « form » levels in musical units. Bob Snyder considers that a « moderate tempo » lies around 100 beats per minute (bpm), whereas the greatest pulse salience can be found around 60-150 bpm[46]. Both affirmations are consistent, and result into the limit of 11.5 seconds, corresponding to approximately 14 beats.

While this approximation is admittedly extremely rough, it is sufficient for the problem at hand, which consists in positioning the different notions in terms of time scale. The correspondence between metrical time and actual time is reported on **Figure 1**.

42 Bob SNYDER, *op. cit.*, 2000, Chapter 1. The table shown in **Figure 2** can be found at the top of p. 12.
43 It is obtained by evaluating the geometric mean of the values immediately surrounding the border between the level of event fusion and the next level.
44 It is obtained by evaluating the geometric mean of the values immediately surrounding the border between the level of melodic and rhythmic grouping and the next level.
45 This is a specific interpretation of the notion of « form ». As we'll see in **Chapter I, Section 3**, « form » may be interpreted differently by other authors.
46 Bob SNYDER, *op. cit.*, 2000, p. 168.

Chapter I, Section 2:
Semiotic units and Morpho-Syntagmatic level (Bimbot & al.).

In regard to Snyder's views, the semiotic unit can be defined as the shortest possible grouping of elements that belongs to the level of « form ». In the context of a « pop » music corpus, it has been found to last approximately 15.5 seconds on average[47], which places it near or above Snyder's limit between short-term and long-term memory. The existence of the semiotic segment is motivated by the need of an optimized, unified description at large scales[48]. The semiotic description of the structure of a music piece is a metaphoric representation of that piece as a sequence of sections reflecting the organization of the whole piece into successive segments or blocks of comparable size, as well as the similarities or equivalence relationships between sections represented by identical semiotic labels. It relies on the hypothesis according to which the choice of Snyder's shortest possible « form » scale will result in a description that reaches the best possible compromise between the regularity of the sectional blocks, the minimality of the set of labels, the accuracy of the decomposition and its coverage.

Table 1.1
Three Levels of Musical Experience

	Events per second	Seconds per event
	16,384	1/16,384
EVENT FUSION	8,192	1/8,192
(early processing)	4,096	1/4,096
	2,048	1/2,048
Functional units =	1,024	1/1,024
individual *events* and	512	1/512
boundaries; pitches,	256	1/256
simultaneous intervals,	128	1/128
loudness changes, etc.	64	1/64
	32	1/32
MELODIC and RHYTHMIC	16	1/16
GROUPING	8	1/8
(short-term memory)	4	1/4
Functional units =	2	1/2
patterns; rhythmic and	1	1
melodic groupings,	1/2	2
phrases.	1/4	4
	1/8	8
	1/16	16
FORM	1/32	32
(long-term memory)	1/64	1 min 4 sec
Functional units =	1/128	2 min 8 sec
large scale *constancies*;	1/256	4 min 16 sec
sections, movements,	1/512	8 min 32 sec
entire pieces.	1/1,024	17 min 4 sec
	1/2,048	34 min 8 sec
	1/4,096	1 hr 8 min 16 sec.

Figure 2. Bob Snyder's three « levels of musical experience ».

The concept of semiotic structure follows the conception of Nicolas Ruwet[49], according to which we approach music as a semiotic system, and focus our interest on the structure of the code. This may result in a level of description of the musical message that does not correspond to that intended by the composer and that does not

47 Frédéric BIMBOT, *op. cit.*, 2011, Section 5.2.1.
48 Frédéric BIMBOT & al., *op. cit.*, 2010. Frédéric BIMBOT & al., *op. cit.*, 2011. Frédéric BIMBOT & al., *op. cit.*, 2012.
49 Nicolas RUWET and Mark EVERIST, « Methods of Analysis in Musicology », *Music Analysis*, VI/1-2 (1987), p. 32.

account for the actual musical language used by the composer[50].

On first approach, such a description consists in a sequence of labels (« A, A, A, B, A, C, C ... »), each label being a reference to an equivalence class. An equivalence class can be made explicit using a model, which will be typical of the class, and from which all instances from the same class can be derived. Due to the sparsity of relations between two semiotic units, description of one unit in regard to another unit may only be done by means of comparison[51]. This results into a sequence of labels, or « signs » as understood by the theory of semiology[52]. While our concept of « semiotic structure » doesn't redefine the notion of « sign » as commonly cited in this field, it tries to specify an estimation of the time scale above which it is possible to consider the existence of discrete segments, i.e. above which the field of semiology may apply[53].

The content of each semiotic unit belongs to the morpho-syntagmatic level or MS level for short. As illustrated on **Figure 1**, the MS level is included inside Snyder's melodic and rhythmic grouping level, a level in which relations between the elements have not yet been filtered down by long-term memory. It is therefore possible to represent the content of a semiotic unit using a system of relations. The nature and function of such relations are strongly related to those underlying implication and realization in Eugene Narmour's model, which in turn is an answer to the problem of « musical expectation »[54].

A typical semiotic unit is considered as usually lasting 16 « snaps », with a snap generally corresponding to two beats. The snap is not to be considered as a unit of measure with which the length of the semiotic unit is evaluated. It is on the contrary derived from it. Given a semiotic unit that's made for instance from eight 4/4 bars, then we face the possibility of identifying a system based on relations between 16 elements, each element lasting by definition one snap. In this case, the snap will last two beats. Given another unit that's made from six 4/4 bars, then we may face the possibility of identifying a system based on relations between 24 elements, each element lasting by definition one snap. In that case, the snap will last one beat[55].

50 This is referred to as the « neutral level » in Jean-Jacques NATTIEZ, *Musicologie Générale et Sémiologie*, Christian Bourgeois, 1987, p. 43.
51 The alternative being a system of relations between units.
52 The notion of semiotic structure is an answer to the problem of music segmentation, see for instance in Kofi AGAWU, *Music as Discourse, Semiotic Adventures in Romantic Music*, Oxford University Press, 2009, p. 142. The problem of segmentation is intrinsic to the field of semiology, as seen in Ferdinand de SAUSSURE, *Cours de Linguistique Générale,* Payot, 1922, p. 98, as cited by Jean-Jacques NATTIEZ, *op. cit.*, 1987, p. 3.
53 Such a time scale also corresponds to Bob Snyder's level of « form ».
54 Frédéric BIMBOT & al., *op. cit.*, 2012, p. 236, see Chapter 2 in particular. For the problem of musical expectation, including Narmour's theories, see **Chapter II, Section 1**.
55 During the course of our previous works on the subject, several reviewers and collaborators have pointed out that the snap may be equivalent to the tactus, as defined in Howard M. BROWN and Claus BOCKMAIER, « Tactus », *Grove Music Online*, Oxford Music Online, Oxford University Press, http://www.oxfordmusiconline.com/ subscriber/ article/grove/music/27354, (accessed on July 8th, 2013). We now realize that it's not the case. The tactus is a « bottom up » notion that helps quantify larger objects. On the contrary, the snap is a « top down » notion that's derived from larger objects.

Chapter I, Section 3:
Concepts derived from music analysis (Schoenberg, Caplin, Monelle).

Both Snyder's levels of musical experience and Bimbot's semiotic units can be put in relation to notions that belong more typically to music analysis. In a composition treatise, Arnold Schoenberg defines and illustrates a number of « structural units »[56]. In a work devoted to analysis of the « classical form », William E. Caplin cites Schoenberg generously and proceeds to refining Schoenberg's notions, which he finds belonging to the practice of *Formenlehre*[57]. Additionally, while studying « transformation » and « generation » of musical elements in a context of considering the relationships between linguistics, semiotics and music, Raymond Monelle provides an overview of several musical objects in relation to their length, some of them being also mentioned by Schoenberg and Caplin[58].

First and foremost are the notions of « period » and « sentence ». According to Schoenberg, both periods and sentences typically last eight measures. Similarly, according to Caplin, they're « normatively an eight-measure structure »[59]. Therefore, their duration is compatible with that of the semiotic unit. Furthermore, according to Schoenberg, both sentence and period are instances of a « complete musical idea ». This notion of a « complete idea » is highly compatible with the independence of the semiotic unit[60].

Periods are described by both Schoenberg and Caplin as being built as the sequence of an « antecedent » and a « consequent », which are qualified by Caplin as « phrases »[61]. Schoenberg doesn't share the same conception of the phrase. For Schoenberg, the duration of a phrase may « vary within wide limits », and last anywhere from 4 beats to 30 beats[62]. As shown on **Figure 1** and **Figure 3**, Caplin also routinely makes use of units he calls « basic idea » and « contrastive idea », each one of them typically lasting a fourth of a period[63].

Sentences are described by Caplin as being built as the sequence of a « presentation » and a « continuation », with the presentation starting with the « basic idea »[64]. This is illustrated on **Figure 4.** Description of the sentence by Schoenberg is less detailed, with the mention of a « basic motive » that may last two bars, and a « continuation » of unspecified length[65].

56 Arnold SCHOENBERG, *op. cit.*, 1967.
57 William E. CAPLIN, *op. cit.*, 1998, p.3.
58 Raymond MONELLE, *op. cit.*, p. 149-150.
59 Arnold SCHOENBERG, *op. cit.*, 1967, p. 20-21. William E. CAPLIN, *op. cit.*, 1998, p. 9-12.
60 In **Chapter II, Section 2**, we'll see how this notion of a « complete musical idea » can be reformulated as a semiotic unit containing a system of relations, these relations being viewed in terms of musical implication.
61 Arnold SCHOENBERG, *op. cit.*, 1967, p. 25. William E. CAPLIN, *op. cit.*, 1998, p. 12.
62 Arnold SCHOENBERG, *op. cit.*, 1967, p. 3-7.
63 William E. CAPLIN, *op. cit.*, 1998, p. 12.
64 William E. CAPLIN, *op. cit.*, 1998, p. 10.
65 Arnold SCHOENBERG, *op. cit.*, 1967, p. 21.

Monelle provides a hierarchical representation of musical units, with a « period » lasting 32 beats[66]. It apparently corresponds to Caplin's period and its duration is compatible with that of our semiotic unit. Similarly to Caplin's period, Monelle's period can be divided in two, this time resulting in an « opening phrase » and a « closing phrase », which makes Monelle's phrases compatible with Caplin's. Each phrase is made from two « subphrases » based on two bars, which are in turn divided into two « feet » lasting two beats. The representation is derived from a study of the grammar in a nursery tune based on a theory of the phonology of the English language[67]. It is remarkably compatible with Schoenberg and Caplin's *Formenlehre*, and possesses the advantage of encompassing low-level units such as the beat.

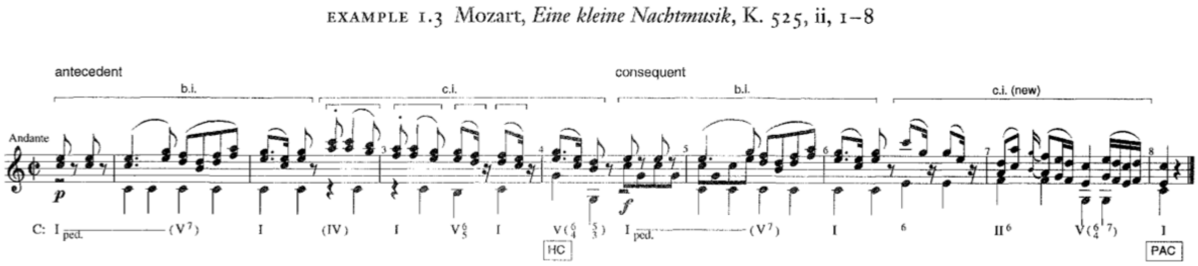

Figure 3. Example of a period as provided by Caplin[68].

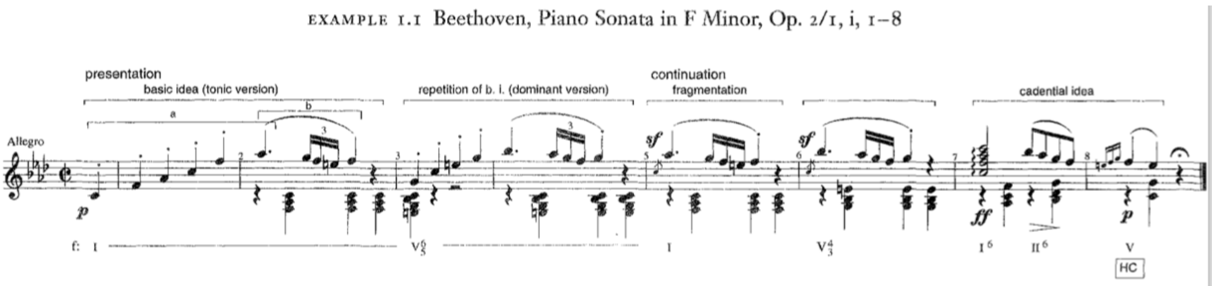

Figure 4. Example of a sentence as provided by Caplin[69].

66 Raymond MONELLE, *op. cit.,* 1992, p. 149-150.

67 Johan SUNDBERG and Bjorn LINDBLOM, « Generative theories in language and music descriptions », *Cognition*, IV (1976), p. 99-122. Noam CHOMSKY and Morris HALLE, *The sound pattern of English*, Harper and Row, 1968.

68 William E. CAPLIN, *op. cit.*, 1998, p. 12. The original piece is Wolfgang A. MOZART, « Serenade Nr. 13 für Streicher in G-Dur. », K. 525, 1787.

69 William E. CAPLIN, *op. cit.*, 1998, p. 10. The original piece is Ludwig Van BEETHOVEN, « Sonate Nr. 1 f-Moll », op. 2, n° 1, 1795.

CHAPTER II:
SYSTEMIC RELATIONS.

In the present Chapter, we focus on the systemic relations inside the semiotic units. We start by examining the notion of musical expectation, after which we introduce the S&C model as a candidate for the description of the systemic relations.

Figure 5, below, summarizes the respective properties of the semiotic structure and the Morpho-Syntagmatic level. In this representation, relations between semiotic units are bi-directional, reflecting their belonging to equivalence classes[70], whereas systemic relations at the MS level, which are conditioned by musical expectation, are directional[71].

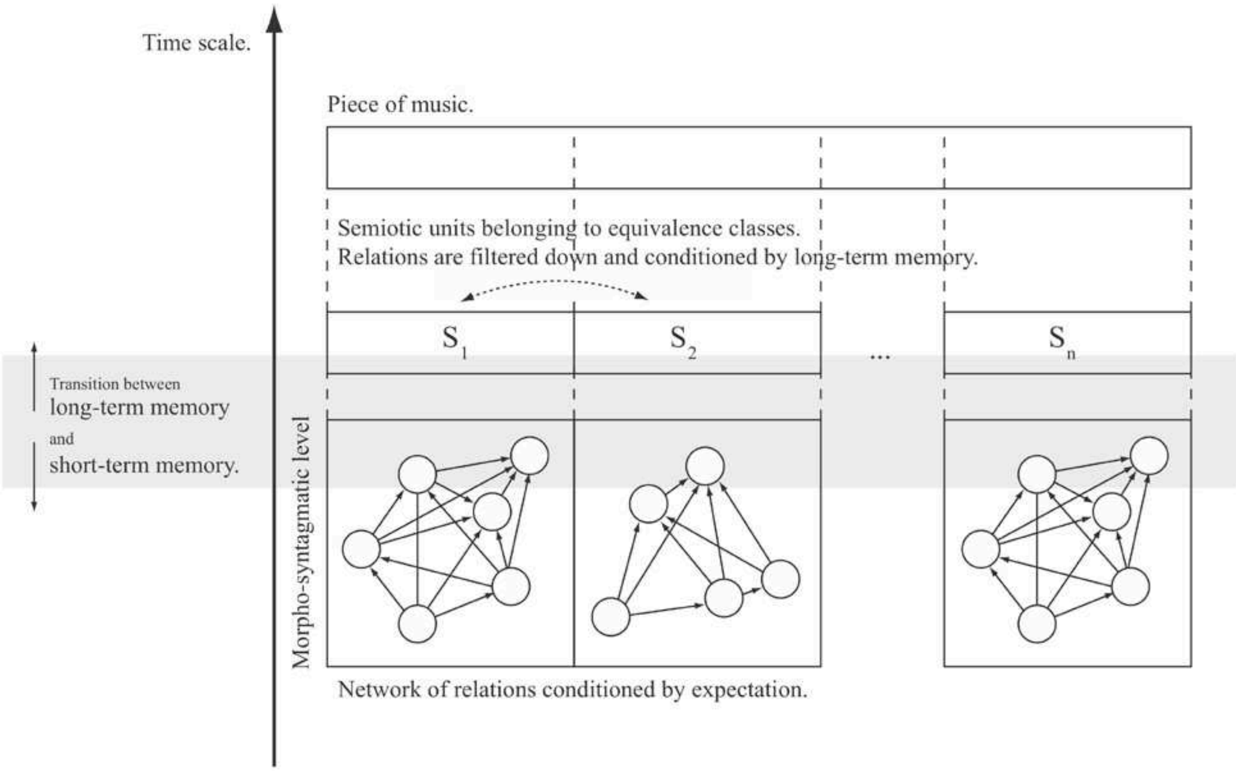

Figure 5. A recapitulation of respective properties of the semiotic structure and MS level.

70 As seen in **Chapter I, Section 2**, class determination of semiotic units is done by way of comparison between the units. Comparison between two units doesn't take into account their order of appearance in the music piece.

71 An element can only be subject to an expectation in regard to the elements it follows.

Chapter II, Section 1: Musical expectation.

II.1.1. State of the art.

The notion of « musical expectation » has prompted the existence of a large corpus of studies, in fields as varied as musical analysis, cognitive psychology and information theory. Most authors provide their own terminology, and sometimes don't make connections with existing literature. The result is a number of terms and notions that may or may not be synonymous, or which may acquire distinct meanings in respect to each other, depending on the publication in which they're found:

- « Analogy »[72].
- « Anticipation »[73].
- « Arousal »[74].
- « Deduction »[75].
- « Directionality »[76].
- « Expectancy », « expectation », « expectedness », and in French « *attente* »[77].
- « Facilitation »[78].
- « Implication / realization »[79].
- « Implication » (independent from realization)[80].
- « Induction »[81].
- « Inertia »[82].
- « Musical force(s) »[83].
- « Previsibility », « predictibility » and « prediction »[84].

72 From the French *analogie*, in Fabien LÉVY, *Complexité grammatologique et complexité aperceptive en musique*, submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy at the EHESS (Jean-Marc Chouvel, Marc Chemillier, directors), Paris, 2003, p. 258.

73 Fabien LÉVY, *op. cit.*, p. 166-167, 178-183, 250-279. William F. THOMPSON, « David Huron, *Sweet anticipation: music and the psychology of expectation* », *Empirical Musicology Review*, II/2, 2007, p. 67-70.

74 Leonard B. MEYER, « Meaning in music and information theory », *Journal of Aesthetics and Art Criticism*, XV/4 (1957), p. 412-424.

75 Eugene NARMOUR, « Music expectation by cognitive rule-mapping », *Music Perception*, XVII/3, 2000, p. 329-398.

76 Vincent ARLETTAZ, *Musica Ficta, une histoire des sensibles du XIII^e^ au XVI^e^ siècle*, Sprimont, Pierre Mardaga éditeur, 2000. Joel LESTER, « Rameau and eighteenth-century harmonic theory », *The Cambridge History of Western Music Theory*, directed by Thomas Christensen, Cambridge, Cambridge University Press, 2002, p. 750-760. Elizabeth H. MARGULIS, « A model of melodic expectation », *Music Perception*, XXII/4 (2005), p. 663-714.

77 Samer ABDALLAH and Mark PLUMBLEY, « Information dynamics: patterns of expectation and surprise in the perception of music », Connection Science, XXI/2-3 (2009), p. 89-117. Rita AIELLO, « David Huron, Sweet anticipation: music and the psychology of expectation. », *Empirical Musicology Review*, II/2 (2007), p. 65-66. Jamshed J. BHARUCHA, *op. cit.,* 1987. James C. CARLSEN, « Some factors which influence melodic expectancy », *Psychomusicology*, I (1981), p. 12-29. Lola CUDDY and Carole LUNNEY, « Expectancies Generated by Melodic Intervals: Perceptual Judgments of Melodic Continuity », *Perception & Psychophysics*, LVII/4 (1995), p. 451-462. Morwaread M. FARBOOD, *A quantitative, parametric model of musical tension*, submitted to the Program in Media Arts and Sciences, School of Architecture and Planning, in partial fulfillment of the requirements for the degree of Doctor of Philosophy at the Massachusetts Institute of Technology (Tod Machover, supervisor), 2006, p. 42, 76. Fabien LÉVY, *op. cit.*, p. 216-235, 250-279. Elizabeth H. MARGULIS, « Surprise and Listening Ahead: Analytical Engagements with Musical Tendencies », *Music Theory Spectrum*, XXIX/2 (2007), p. 197-217. Mark A. SCHMUKLER, « Expectation in music: Investigation of melodic and harmonic processes », *Music Perception*, VII (1989) p. 109-150. Yizhak SADAÏ, « Les aspects systémiques et énigmatiques de la musique tonale, points d'appui et points d'interrogation », *International Review of the Aesthetics and Sociology of Music,* XVII/2 (1986), p. 299-332. William F. THOMPSON, *op. cit.*, 2007.

78 Jamshed J. BHARUCHA, « Music Cognition and Perceptual Facilitation: A Connectionist Framework », *Music Perception: An Interdisciplinary Journal*, V/1 (1987), p. 1-30. Fabien LÉVY, *op. cit.*, 2003, p. 262. Elizabeth H. MARGULIS, *op. cit.*, 2005.

79 Jamshed J. BHARUCHA, *op. cit.*, 1987. Naomi CUMMING, *op. cit.*, 1992. Morwaread M. FARBOOD, *op. cit.*, 2006. Elizabeth H. MARGULIS, *op. cit.*, 2005. Eugene NARMOUR, *op. cit.*, 2000. Bob SNYDER, *op. cit.*, p. 148. William F. THOMPSON, *op. cit.*, 2007.

80 Leonard B. MEYER, *op. cit.*, 1957.

81 Fabien LÉVY, *op. cit.*, 2003, p. 255, 258. Eugene NARMOUR, *op. cit.*, 2000. William F. THOMPSON, *op. cit.*, 2007.

82 Rita AIELLO, *op. cit.*, 2007. Steve LARSON et Leigh VANHANDEL, « Measuring musical forces », *Music Perception*, XXIII/2 (2005), p. 119-136. William F. THOMPSON, *op. cit.*, 2007.

83 Steve LARSON et Leigh VANHANDEL, « Measuring musical forces », *Music Perception*, XXIII/2 (2005), p. 119-136.

84 Rita AIELLO, *op. cit.*, 2007. Lejaren HILLER and Ramon FULLER, « Structure and Information in Webern's Symphonie, Op. 21 », *Journal of Music Theory*, XI/1 (1967), p. 60-115. Leon KNOPOFF et William HUTCHINSON, « Information theory for music continua », *Journal of Music Theory*, 25th Anniversary Issue, XXV/1 (1981), p. 17-44. Fabien LÉVY, *op. cit.*, 2003, p. 250-271. Elizabeth H. MARGULIS et Andrew P. BEATTY, « Musical style, psychoaesthetics, and prospects for entropy as an analytic tool », *Computer Music Journal*, XXXII/4 (2008), p. 64-78. Leonard B. MEYER, *op. cit.*, 1957. John L. SNYDER, « Entropy as a measure of musical

- « Resolution »[85].
- « Tension / release », « tension / relaxation »[86].

Some other terms pose particular problems, such as « closure », which is sometimes used as the ending of the « expectation » process[87], and sometimes as a group boundary[88], two interpretations that may not be contradictory, but that are certainly not synonymous. To make things even more difficult, these notions are found to be routinely mentioned in relation to concepts originating from the field of information theory, with the notion of « entropy » being a distinct favorite[89].

Hybridization of information theory and humanities naturally results into the birth of yet other numerous notions, most notably a wealth of variations upon the notion of entropy, modified for the need of description of musical content[90]. There may be a number of ways to interpret and synthesize such a wealth of information, and literature indeed provides several such syntheses, the mere abundance of which being itself a problem. We proceed to distinguish four trends[91].

style: the influence of a priori assumptions », *Music Theory Spectrum*, XII/1 (1990), p. 121-160. William F. THOMPSON, *op. cit.*, 2007. Joseph E. YOUNGBLOOD, « Style as information », *Journal of Music Theory*, II/1 (1958), p. 24-35.

85 Vincent ARLETTAZ, *op. cit.*, 2000. Jamshed J. BHARUCHA, *op. cit.*, 1987. Naomi CUMMING, *op. cit.*, 1992. Morwaread M. FARBOOD, *op. cit.*, 2006, p. 23, 32. Elizabeth H. MARGULIS, *op. cit.*, 2005. Julie RUSHTON, « Resolution », *Grove Music Online*, Oxford Music Online, Oxford University Press, http://www.oxfordmusiconline.com/ subscriber/article/grove/music/23234 (accessed on July 1st, 2013). Yizhak SADAÏ, *op. cit.*, 1986.

86 Amongst many others, in Rita AIELLO, *op. cit.*, 2007. Morwaread M. FARBOOD, *op. cit.*, 2006, p. 93-110. Fred LERDAHL and Ray JACKENDOFF, *op. cit.*, 1983, p.184. William F. THOMPSON, *op. cit.*, 2007.

87 Amongst many others, in Kofi AGAWU, « Theory and Practice in the Analysis of the Nineteenth-Century Lied, *Music Analysis*, XI/1 (1992) », p. 3-36. Elizabeth H. MARGULIS, *op. cit.*, 2007.

88 Bob SNYDER, *Music and Memory*, M.I.T. Press, 2000, p. 59-67.Even though he term is used in connection with grouping, it is interpreted as group boundary, whereas in Fred LERDAHL and Ray JACKENDOFF, *op. cit.*, 1983, still in connection with grouping, it is interpreted as the ending of the expectation process.

89 Samer ABDALLAH and Mark PLUMBLEY, *op. cit.*, 2009. Lejaren HILLER and Ramon FULLER, *op. cit.*, 1967. Leon KNOPOFF et William HUTCHINSON, *op. cit.*, 1981. Fabien LÉVY, *op. cit.*, 2003, p. 165. Elizabeth H. MARGULIS and Andrew P. BEATTY, *op. cit.*, 2008. Leonard B. MEYER, *op. cit.*, 1957. John L. SNYDER, *op. cit.*, 1990. Joseph E. YOUNGBLOOD, *op. cit.*, 1958.

90 A spectacular example in terms of the sheer number of variations being found in Sarah E. CULPEPPER, *Musical time and information theory entropy*, submitted in partial fulfillment of the requirements for the Master of Arts degree in Music in the Graduate College of The University of Iowa (Robert C. Cook, supervisor), 2010, p. iv.

91 For an alternative, see the concise and clear state of the art provided by Morwaread M. FARBOOD, *op. cit.*, 2006, p. 29-42.

- The first trend includes publications from the 1950's that are concerned with objectivization and rationalization of the concept of what they call « arousal », « uncertainty », or « nonconfirmation of a prediction » using information theory. This concerns three journal articles by respectively Meyer (1957), Younblood (1958) and Krahenbuehl & Coons (1959) [92] .

- The second trend concerns the more recent publications that include a step-by-step music analysis process, such as Lerdahl & Jackendoff's « generative theory of tonal music » (1983) [93] and Narmour's « implication-realization » model (1992)[94]. Similarly to our approach of semiotic structure determination, this type of works provides a set of manual operations that can be replicated and aim towards a unique result given that the starting point is the same.

- The third trend provides quantitative models based on computer algorithms that evaluate descriptor values, an approach that's similar to Music Information Retrieval. Margulis' « model of melodic expectation » (2005), and Farbood's « quantitative, parametric model of musical tension » (2006) [95].

- The fourth trend groups generalist theories whose focus lies neither in step-by-step processes nor in quantitative operations, and may include elements such as cognition and neurophysiology. This includes Larson's « musical forces » (1992-2004) and Huron's « theory of general expectation » (2007) [96] .

II.1.2. Eugene Narmour's works on iterative rules.

Narmour's works, which belong to the second trend, initially stand on a very distinctive viewpoint. In the author's terms:

> « What we know about expectations is based too heavily upon percepts, introspection, internalizations, and so on, with all the insoluble epistemological problems so well known to phenomenologists. Because of this, it is clear that the concept of expectation taken as an exclusive basis for building an analytical system has a fatal flaw in the theoretical sense because it cannot be formulated in falsifiable terms – the *sine qua non* of a genuine theory. Implications, on the other hand, can be based on objectively specifiable evidence (the printed notes themselves), and their realisations can be precisely defined. » [97]

Such a point of view is fundamental to Narmour's method. In particular, it results into a capital hypothesis behind Narmour's initial approach, consisting in a temporary dismissal of the difference between the perceptual and logical contexts[98]. We share Narmour's point of view in the sense that we consider this temporary dismissal as an hypothesis underlying the present work.

The « implications » themselves will be formalized into « two formal universal hypotheses ». Given a set of « forms », « intervallic patterns » or « pitch elements », Narmour writes:

1. $A + A \rightarrow A$.
2. $A + B \rightarrow C$.

Or, with words:

1. « When form (A + A), intervallic patterns (A + A), or pitch elements (a + a) of a given melody are similar (A, A, or a), the listener subconsciously or consciously infers some kind of repetition of pattern, element, or form. »

92 In chronological order: Leonard B. MEYER, *op. cit.*, 1957. Joseph E. YOUNGBLOOD, *op. cit.*, 1958. David KRAHENBUEHL et Edgar COONS, « Information as a measure of experience in music », *Journal of Aesthetics and Art Criticism*, XVII/4 (1959), p. 510-522.
93 More particularly the chapters about « prolongational reduction », which specifically deal with « tension » and « relaxation », see Fred LERDAHL and Ray JACKENDOFF, *op. cit.*, 1983, p. 179-249.
94 Eugene NARMOUR, *op. cit.*, 1990. Eugene NARMOUR, *The Analysis and Cognition of Melodic Complexity: the Implication-Realization Model*, University of Chicago Press, 1992.
95 Elizabeth H. MARGULIS, *op. cit.*, 2005. Morwaread M. FARBOOD, *op. cit.*, 2006, p. 29-42.
96 Steve LARSON and Leigh VANHANDEL, *op. cit.*, 2005. David HURON, *op. cit.*, 2006.
97 Eugene NARMOUR, *op. cit.*, 1992, p. 355.
98 Eugene NARMOUR, *op. cit.*, 1977, p. 137, as cited by Naomi CUMMING, *op. cit.*, 1992, p. 356.

2. « When form, intervallic patterns, or pitch elements are different (A + B, A + B, a + b), the listener subconsciously or consciously infers some implied change in form, pattern or element (C, C, or c) .» [99]

An immediate consequence of these two fundamental formal hypotheses is the existence of a possible « denial » of the implication projected onto the third element. In sequences such as {A, A, B} and {A, B, B}, the third element « denies » the implication projected by the first two elements. This results into the basics of Narmour's « implication-realization » model of melodic expectation. In **Chapter II, Section 2**, we'll formulate a similar hypothesis in the context of the « system & contrast » model, with specific results.

The two hypotheses are based on the identification of « similar » and « different » elements, be they « forms », « intervallic patterns » or « melodies ». This implies a reflection on the notions of « similarity » and « difference », of which Narmour later provides a typology[100].

In a later contribution, Narmour focuses on the notion of « rule-mapping », an extension of the implication-realization model[101]. Rule-mapping, or the invocation of rules, occurs when it is possible to link elements with relations that project an implication onto other elements. This is illustrated in **Figure 6**, where, according to Narmour, the rule can be expressed as « Expect to add descending diatonic seconds at the beginning of each repetition ». The content of sequences noted as A^1 through A^5 can therefore being deduced from sequence A^0 once their first note is known.

In Narmour's own admission, rule-mapping is based on iterative rules[102], which is a natural consequence of the two formal hypotheses used for the implication-realization model. In **Chapter II, Section 2**, our following of a different formal hypothesis will result into rules that are not iterative.

In regard to our concerns, Narmour's works appear to be particularly relevant, be it in terms of the hypotheses it is based on or in its recurring considerations about « similarity » and « difference ». Therefore, when dealing with musical expectation, we will from now on restrict ourselves to the use of Narmour's terminology, including possible derivatives and consequences.

99 Eugene NARMOUR, *op. cit.*, 1990, p. 3, as cited by Naomi CUMMING, *op. cit.*, 1992, p. 357.
100 Eugene NARMOUR, *op. cit.*, 2000, p. 357.
101 Eugene NARMOUR, *op. cit.*, 2000.
102 Eugene NARMOUR, *op. cit.*, 2000, first sentence from the abstract.

Chapter II, Section 2:
The square form of the System & Contrast model

II.2.1. Presentation of the S&C model.

The « System & Contrast » model or « S&C » model provides a standard for the network of relations at the Morpho-Syntagmatic level. It can be used either to describe the totality of the semiotic segment, or only subsets of the segment. In its simplest form, called the « square form », it is based on four « morphological units » and a number of relations that project an implication onto the fourth unit[103].

Fig. 3. Complex sequences based on the same motive. Bach, Prelude 14, *Well-Tempered Clavier*, 1, mm. 1–3. P^0 = process of similar intervals; (R^0) = retrospective reversal of similar intervals; (R^+) = retrospective reversal of small to large interval.

Figure 6. An example of Narmour's rule-mapping, formulated as « Expect to add descending diatonic seconds at the beginning of each repetition »[104].

103 See Frédéric BIMBOT & al., *op. cit.*, 2012, Section 3.1, as well as Frédéric BIMBOT & al., « Complementary report to the Article "Semiotic structure labeling of music pieces: concepts, methods and annotation conventions" (Proceedings ISMIR 2012) », *IRISA Internal Report n° PI-1996, 2012, hal-00713196, version 1* and Frédéric BIMBOT, Emmanuel DERUTY, Gabriel SARGENT, Emmanuel VINCENT, « System & Contrast : a Polymorphous Model of the Inner Organization of Structural Segments within Music Pieces (Original Extensive Version) ». *IRISA Internal Report n° PI-1999, 2012, hal-00868398, version 1.*

104 Eugene NARMOUR, *op. cit.*, 2000, p. 340. Original piece is Johann S. BACH, « Präludium Nr. 14 », *Das Wohltemperierte Klavier, Teil 1*, BWV 859, 1722.

The fundamental hypothesis underlying the S&C model in its square form can be expressed as:

> « Given a set of four consecutive units, the first three units project an implication onto the fourth unit. This implication is realized when {unit 4 is to unit 3 what unit 2 is to unit 1} and {unit 4 is to unit 2 what unit 3 is to unit 1}. Conversely, it is denied when {unit 4 is not to unit 3 what unit 2 is to unit 1} or {unit 4 is not to unit 2 what unit 3 is to unit 1}. »[105]

Such a hypothesis may at first glance appear to be quite complex, but is in fact very natural. It has been qualified as « anticipation by way of induction or analogy »[106], and can be illustrated as shown on **Figure 7**, below.

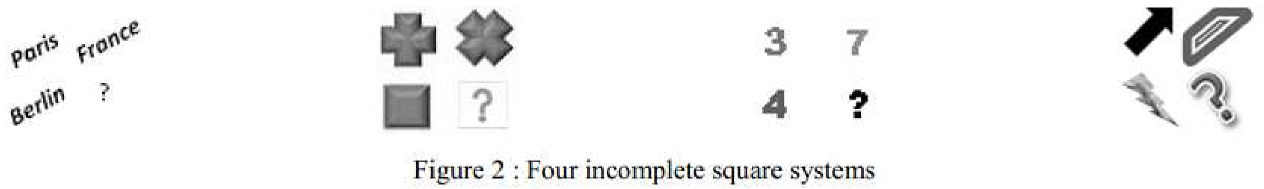

Figure 7. Toy illustrations of implications in the square form of the S&C model[107].

In these examples, implications projected onto the fourth unit result into the expectation of, respectively « Germany », a square rotated by 45°, « 8 », and a shape that's different from the third one but that follows the same orientation. These examples illustrate a temporary dismissal of the differences between perceptual and logical contexts, a position which, as seen in **Chapter 2**, **Section 1**, strongly recalls Narmour's views on implication.

We refer to the four consecutive units as $\{x_{00}, x_{01}, x_{10}, x_{11}\}$. As illustrated on **Figure 8, top,** we write the relation between x_{00} and x_{01} as $x_{01} = f(x_{00})$, and the relation between x_{00} and x_{10} as $x_{10} = g(x_{00})$. Following our fundamental hypothesis, the implication projected onto the fourth element is realized when:

(1) $\begin{cases} x_{11} = f(x_{10}) \\ x_{11} = g(x_{01}) \end{cases}$

Conversely, the implication is denied when:

(2) $\left| \begin{array}{l} x_{11} \neq f(x_{10}) \\ x_{11} \neq g(x_{01}) \end{array} \right.$

105 The hypothesis is an equivalent to Narmour's two fundamental hypotheses as cited in **Chapter II**, **Section 1**.

106 In the original French, *Anticipation par induction ou par analogie*, see Fabien LÉVY, *op. cit.*, 2003, p. 258, which in turns cites C.N.R.S., « Dossiers scientifiques: Sciences Cognitives », *Le courrier du C.N.R.S.*, LXIX, 1992.

107 The Figure is captured from Frédéric BIMBOT, Emmanuel DERUTY, Gabriel SARGENT and Emmanuel VINCENT, « Complementary report to the Article "Semiotic structure labeling of music pieces: concepts, methods and annotation conventions" (Proceedings ISMIR 2012) », *op. cit.*, 2012.

The term « contrast » refers to the logical state of the fourth element in regards to the implication. A realization will result into a null contrast (0). Conversely, a denial will result into a non-null contrast. Additionally, a contrast relation γ is introduced, which describes the difference between the projected and actual x_{11}.

The contrast relation γ is defined as follows. Let's suppose a « diagonal » relation *k*, defined as $x_{11}=k(x_{00})$. It describes the relation between the actual x_{11} and x_{00}. On the other hand $(f\circ g)(x_{00})$, represents the projected x_{11}. The contrast relation γ is defined formally by $\gamma=k\circ(f\circ g)^{-1}$, which represents the « difference » between the diagonal relation *k* and $f\circ g$, i.e. the difference between the projected and actual x_{11}. In case of realization, γ = *id.*, where *id.* is the identity. Conversely, in case of denial, γ ≠ *id.*

Figure 8, middle, schematically illustrates the case where the contrast value is null and γ = *id.* In this case, the system is said to be in a non-contrastive state. **Figure 8, bottom**, schematically illustrates the case where the contrast value is not null and γ ≠ *id*. In that case, the system is said to be in a contrastive state. Notice the use of the notation « $\overline{x_{11}}$ » when γ ≠ *id*. and the actual x_{11} is not as projected. This leads to a first significant property of the S&C model in its square form. Given its potentially contrastive state and its number of morphological elements, it encapsulates the description of musical units as periods and sentences[108]. **Figures 9** and **Figure 10** respectively illustrate the description of a period and a sentence using the S&C model. As illustrated on **Figure 11**, it is also well suited to the description of many « pop » music tracks, whose semiotic units can often be divided into four morphological units[109].

II.2.2. The S&C model compared to iterative rule-based models.

Another significant property of the S&C model lies in the fact that it's « natively » suited to the description of a network of relations based on the independent evolution of two sets of musical parameters. Considering the period example in **Figure 9**, one can roughly describe *f* as a change in the melodic pattern as well as in the harmony. On the other hand, *g* can be described as the addition of a voice during the pickup, along with a change in dynamics. The system of relations formed by the period uses independently the two sets of parameters.

Schematically, the corresponding difference between the hypotheses respectively underlying the implication-realization and the S&C model can be represented as seen in **Figure 12**, in which is shown instances of systems illustrating both hypotheses in a state where the contrast function is the identity (no denial). On the left, whereas the three-unit system deduced from Narmour's hypotheses is indeed based on two parameters (size and hue), they're mandatorily used in conjunction to each other, resulting into an iterative rule[110]. On the right, both parameters are allowed to evolve independently.

108 The square S&C model includes implications and either the realization or denial of these implications. Use of the square S&C model for the description of a semiotic therefore results into the description of a « complete musical idea » as formulated by Arnold Schoenberg (see **Chapter I, Section 3)**, with the « cadential idea » being an important part of the contrast.

109 The square S&C model also possesses a number of common points with Adam Ockelford's « secondary zygonic relationships », see Adam OCKELFORD, *Repetition in Music: Theoretical and Metatheoretical Perspectives*, Ashgate Publishing Ltd., 2005, p. 23. However, we're reluctant to draw bridges between our point of view and Ockelford's. This is mainly due to the essentially subjective conclusions Ockelford draws from his analyses, such as a the finding of a « connotation of spirituality from similarities to J. S. Bach fugues », as read in Adam OCKELFORD, « Relating Musical Structure and Content to Aesthetic Response: A Model and Analysis of Beethoven's Piano Sonata Op. 110 », *Journal of the Royal Musical Association*, CXXX/1 (2005), p. 109-110.

110 In this perspective, the title of Eugene NARMOUR, *op. cit.*, 2000, « Music Expectation by Cognitive Rule-Mapping », might almost be reformulated as « Use of iterative rule-based implication models for the description of music ».

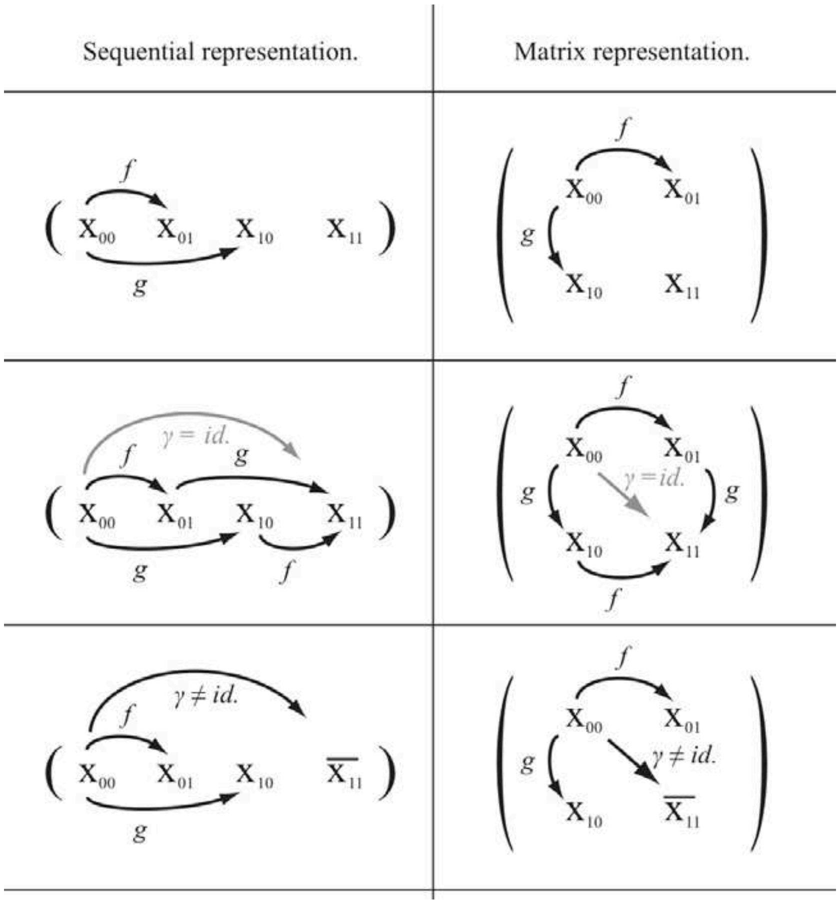

Figure 8. The S&C model in its square form. Top, the two fundamental relations. Middle, representation of the non-contrastive state. Bottom, representation of the contrastive state.

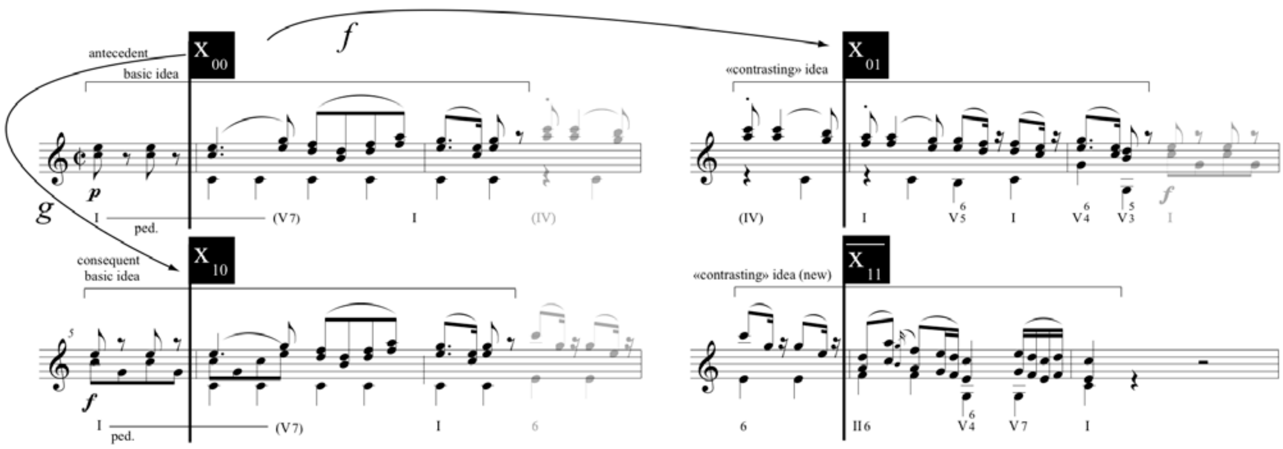

Figure 9. Description of a period using the S&C model in its square form[111].

111 W.A. MOZART, « Serenade Nr. 13 für Streicher in G-Dur », K. 525, 1787. Transcription from William E. CAPLIN, *Classical form*, Oxford University Press, 1998, p. 12. See **Figure 3** for the transcription as originally presented. This particular presentation is borrowed from Frédéric BIMBOT & al., « System & Contrast: A Polymorphous Model Of The Inner Organization Of Structural Segments Within Music Pieces », *op. cit.*

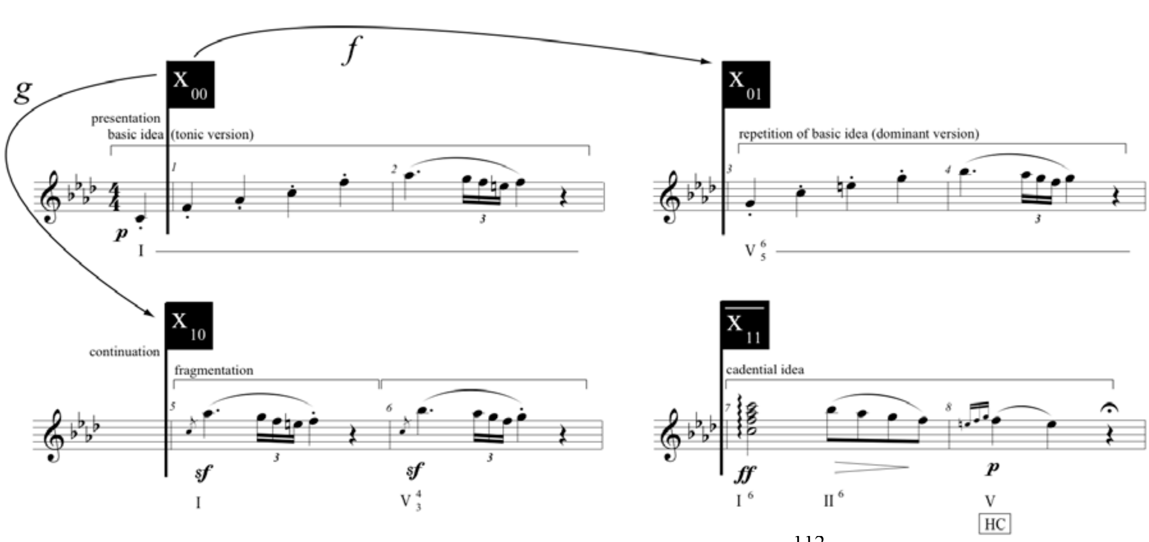

Figure 10. Description of a sentence using the S&C model in its square form[112].

Figure 11. Description of a period-like semiotic unit from Britney Spears' « Heaven on Earth »[113] using the S&C model.

112 Ludwig Van BEETHOVEN, « Sonate Nr. 1 f-Moll », op. 2, n° 1, 1795. Transcription from William E. CAPLIN, *Classical form*, Oxford University Press, 1998, p. 10. See **Figure 4** for the transcription as originally presented. This particular presentation is borrowed from Frédéric BIMBOT & al., « System & Contrast: A Polymorphous Model Of The Inner Organization Of Structural Segments Within Music Pieces », *op. cit.*

113 Britney SPEARS, « Heaven on Earth », *Blackout*, Jive, 2007, 2'33-3'03. Transcription made by the author and borrowed from Frédéric BIMBOT & al., « System & Contrast: A Polymorphous Model Of The Inner Organization Of Structural Segments Within Music Pieces », *op. cit.*

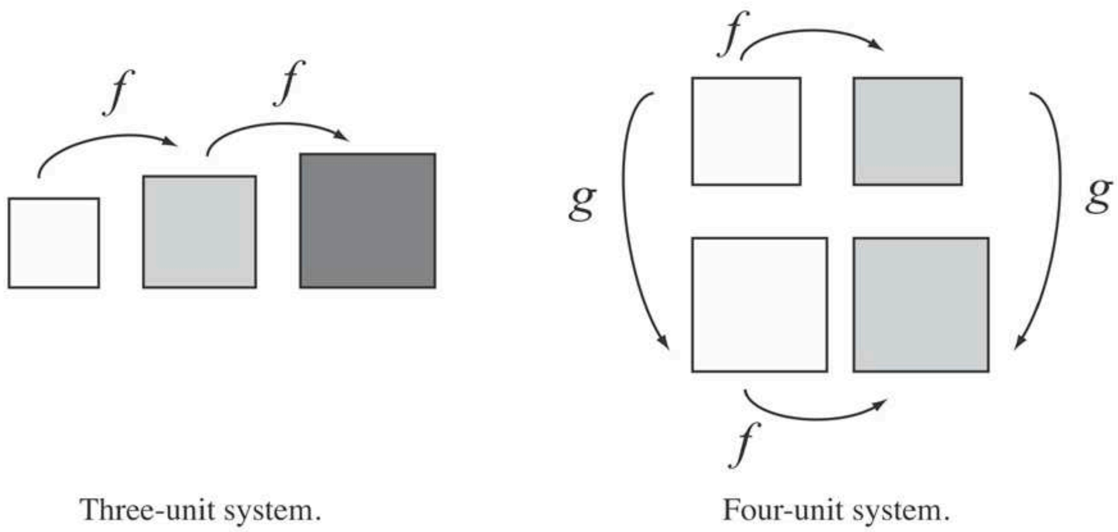

Figure 12. Comparison between a three-unit and a four-unit system. The three-unit system results into an iterative rule even if it's based on different parameters, whereas the four-unit system permits independent evolutions of two different parameters.

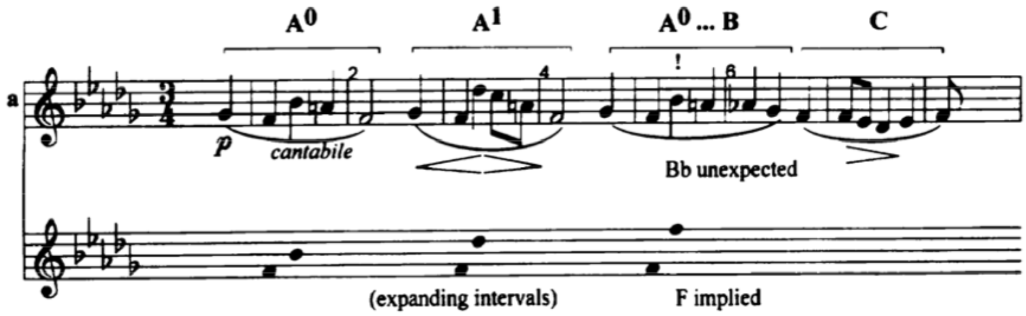

Figure 13. Description of an extract from César Franck's « Symphonie en ré mineur »[114] using an iterative rule based on three units. Denial lies in the third unit.

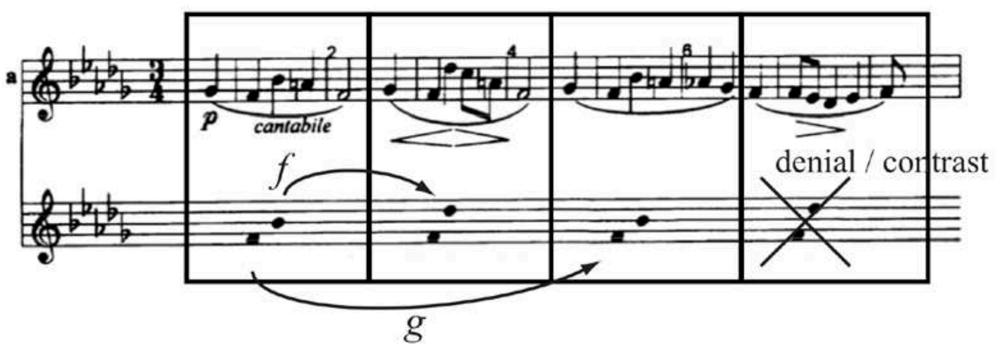

Figure 14. Description of the same extract using the S&C model. Denial lies in the fourth group, and the fourth group is not left aside.

In practice, use of one model instead of the other results in two different descriptions of a given music extract. In **Figure 13**, Narmour uses a three-unit, iterative rule-based model to characterize the « Bb » from the third group as a denial, as opposed to an implied « F ». Indeed, according to such a model, $x_2 = f(x_1)$ (interval « F-Bb »

114 César FRANCK, « Symphonie en ré mineur », 1889, II, bars 17-24. Transcription from Eugene NARMOUR, *op. cit.*, 2000, p. 353.

becomes interval « F-D ») implies $x_3 = f(x_2)$ (interval « F-D » becomes interval « F-F »), with $x_3 \neq f(x_2)$ (interval « F-D » becomes interval « F-Bb ») resulting into a denial. In **Figure 14**, we use the S&C model to describe the same extract. According to this model, the « Bb » is not unexpected, since it is not subject to an implication. Denial lies instead in the fourth unit, where, in place of « G, F, Bb », the notes from the first three beats of each group are « F, F, Eb, D ». Though we have reasons to think that the contradiction is only apparent and will address the issue in our planned PhD, the solution is not provided in the context of this work.

II.2.3. Encapsulation of the four-unit, iterative rule-based model by the S&C model.

Yet another significant property of the system & contrast model in its square form lies in the fact that it encapsulates the four-unit, iterative rule-based model. **Figure 15** shows an extract from Franck Sinatra's « Strangers in the Night », described using the iterative rule-based model. The relation *f* can be formulated as the downward diatonic transposition by one degree, and the fourth elements constitutes a denial. **Figure 16** shows the same extract, this time described using the S&C model. This description is equivalent to the previous one, with $g = f \circ f$ and the contrast lying on the same unit.

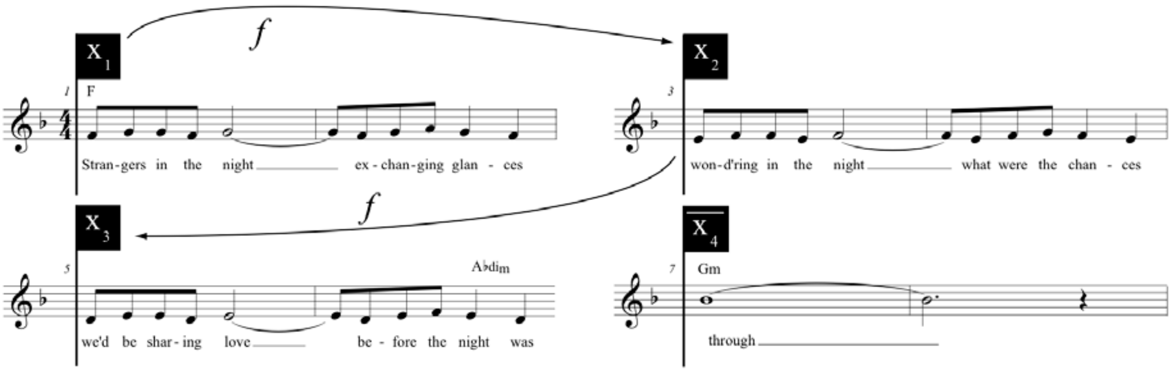

Figure 15. Description of an extract from Franck Sinatra's « Strangers in the Night »[115] using an iterative rule-based model.

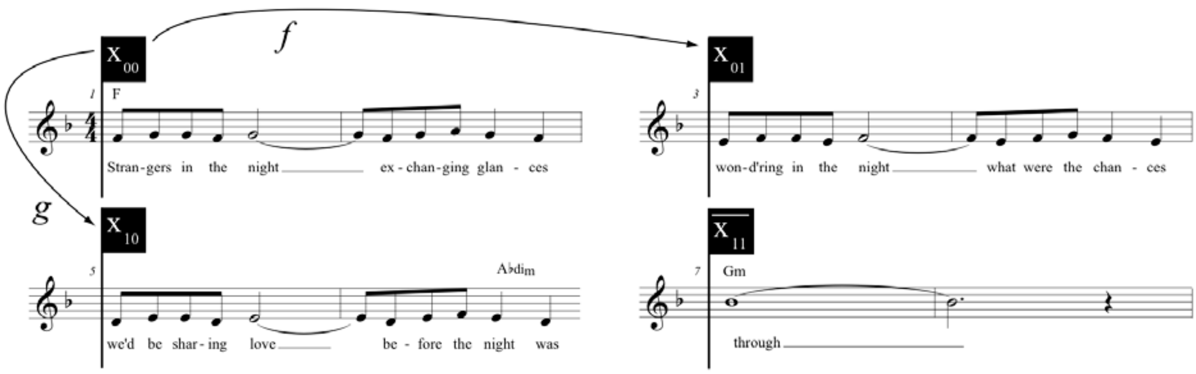

Figure 16. Description of the same extract using the S&C model.

115 Franck SINATRA, « Strangers in the Night », Reprise, 1966. Transcription copied from Franck SINATRA, *Strangers in the Night*, Universal Music Publ. Group / Hal Leonard Corp., 1966-2011, p. 2.

CHAPTER III:
ON MODELS AND DESCRIPTIONS.

Chapter II results into a first approach of the square S&C model. Before studying the S&C model in more details, we first dig a little bit into the underlying principles that guide the S&C analysis. We do so by focusing on consequences brought by the basic idea that consists in providing a simple description for a given music extract or piece. This is done by considering Ockham's « razor » principle of simplicity as an hypothesis.

As will be seen in **Chapter IV**, this approach proves to be indispensable in the perspective of defining additional forms of the S&C model[116] while being able to address the problem of potentially conflicting implications. It will lead to the introduction of the « Minimum Description Length » principle or MDL for short, a principle which belongs to the field of information theory and is generally described using heavy mathematical formalism[117]. In this document, we consider MDL from an epistemological point of view, without formalism. We follow the point of view according to which MDL is an answer to the problem of « model selection », which in turn derives from a modern interpretation of Ockham's razor[118].

We then proceed to show the relationships between MDL and the S&C model. In doing so, we suggest that the principles underlying MDL can serve as a framework to obtain a proper description of a semiotic segment or more generally a music excerpt[119] by means of the S&C model. The same principles will be shown to have the potential to be an interesting tool in the more general field of music analysis. The MDL principle will also provide a decomposition of the observed data into a systemic and a « residual » part.

While this Chapter focuses on the principles involved, **Chapter IV** will put these principles into application, with the specification of non-square forms of the S&C model as a result.

116 Specifically, forms with a number of morphological units that's different from 4.

117 Bibliography for the MDL principle is abundant and mainly based on formalism. In the context of the present work, one may consider the following. The seminal article, Jorma RISSANEN, *op. cit.*, 1978. A clear and understandable introduction by Peter D. GRÜNWALD, Jay INJAE MYUNG and Mark A. PITT, *Advances in Minimum Description Length*, M.I.T. Press, 2005, p. 5. A thesis whose introduction reflects on the epistemology of MDL, Peter D. GRÜNWALD, *op. cit.*, 1998. The first mention of the MDL in regards to the S&C model can be found in Frédéric BIMBOT & al., « System & Contrast: A Polymorphous Model Of The Inner Organization Of Structural Segments Within Music Pieces », *op. cit.*

118 Peter D. GRÜNWALD, *op. cit.*, 1998, p. v.

119 A music excerpt that complies to the time scale specifications mentioned in **Chapter 1**.

Chapter III, Section 1:
MDL and preferred descriptions.

According to Ockham's « razor » principle, « a plurality should only be postulated if there is some good reason, experience, or infallible authority for it »[120]. Modern mathematical adaptation of this principle results in stating that « if several explanations [...] of a given phenomenon [...] exist, then we should pick the simplest [...] one »[121]. In a musical context, we're reluctant to use the word « explanation », as it might be connoted and potentially imply that we refer to the composer's intentions, which is not the case[122]. As seen throughout the previous chapters, we prefer to use the word « description ». In the same context, the « phenomenon », also referred to as « data », is naturally the music piece or excerpt.

Kolmogorov's theory of complexity[123] is a branch of information theory, in the framework of which simplicity and compacity are somehow synonyms and interchangeable. Such an hypothesis proceeds from the fact that a simple sequence such as, for instance, {1, 2, 3, 4, 5, 6, 7, 8, 9, 10}, can be reformulated in a compact way as {1, 2 ... 10}, whereas there is no compact equivalent for a complex sequence such as {1, 5, 10, 3, 8, 4, 6, 7, 2, 9}. Therefore, picking the « simplest » explanation or description is equivalent to picking the shortest one. Throughout the present section and all that follow, we will indeed consider « simple » and « short » as equivalent.

Central to the field of Kolmogorov's theory is the notion of Kolmogorov entropy. In a nutshell, it postulates that given data, there is a lower limit to the size of the simplest or shortest description we can draw from this data. The said limit depends on the data, and can be used as a quantitative descriptor for the data's complexity. As a result, following the mathematical adaptation of Ockham's principle, given a musical excerpt or piece, then we should devote our efforts to finding the description whose size is described by the piece's Kolmogorov entropy, in other words the simplest possible one.

120 In the original Latin, « *Nulla pluralitas est pondenda nisi per rationem vel experiantiam vel auctoritatem illius, qui non potest falli nec errare, potest convivi.* », William of OCKHAM, *op. cit.*, 1323, as cited by Peter D. GRÜNWALD, *op. cit.*, 1998, p. v.

121 Ming LI and Paul VITÁNYI, *An Introduction to Kolmogorov Complexity and Its Applications,* 3rd edition, Springer, 2008, as cited by Peter D. GRÜNWALD, *op. cit.*, 1998, p. ix. The complete sentence is « if several explanations (programs) of a given phenomenon (data) exist, then we should pick the simplest (shortest) one ».

122 This is detailed in the **Introduction**.

123 Jean-Paul DELAHAYE, « Théorie de la complexité de Kolmogorov », *Encyclopædia Universalis en ligne*, http://www.universalis-edu.com/encyclopedie//theorie-de-la-complexite-de-kolmogorov/ (accessed on July 22nd, 2013). The corresponding seminal paper is Andrey KOLMOGOROV, « On tables of random numbers », *Sankhyā: The Indian Journal of Statistics*, XXV/4 (1963), p. 369-376.

However, trying to find a simplest possible description leads to two major problems:

- For any given data, although the value of the Kolmogorov entropy theoretically exists, it can't be accessed. It can only be estimated. This is equivalent to stating that given data, be it a musical piece or otherwise, access to its simplest description is impossible.
- Given a number of data sets, for instance several different musical excerpts, each description as obtained by following the guideline according to which we should look for the simplest one may resort to an analytic process that's specific to the excerpt. For example, the simplest description we can imagine for a Viennese classical *aria* will very likely address relationships between the soloist and the orchestra in the context of an harmonic language, whereas the simplest description we can provide for Ligeti's *toccata*-like solo piano piece « The Devil's Staircase »[124] will be based on a very different set of considerations, more likely in relation to arpeggiated sequences of inharmonic aggregates. In other words, given the aforementioned guideline, there might be as many ways to describe music pieces as there are music pieces, which in turn defeats the original purpose of simplicity.

The solution to both problems lies in the use of a limited number of models[125]. Given data, we do not look for the simplest or shortest possible description, we look for the available model (from amongst a limited list) that results in the simplest or shortest description. Therefore, instead of being previously confronted to a description problem, we now have to deal with a problem of model selection[126].

The problem of model selection, unlike the determination of the simplest or shortest description, can be solved generically using the « Minimum Description Length » principle[127], which can be summed up as follows:

> « The Minimum Description Length (MDL) Principle is a relatively recent method for inductive inference that provides a generic solution to the model selection problem. MDL is based on the following insight: any regularity in the data can be used to compress the data, i.e. to describe it using fewer symbols than the number of symbols needed to describe the data literally. The more regularities there are, the more the data can be compressed. Equating ‘learning’ with ‘finding regularity’, we can therefore say that the more we are able to compress the data, the more we have learned about the data. » [128]

124 György LIGETI, *Études pour piano*, vol. 2, Schott Musik International, 1986.
125 Such as Narmour's inference rule-based model, or such as the S&C model.
126 An illustration of a situation where selection of a model could be performed lies in Subsection II.2.2.
127 Introduced in Jorma RISSANEN, *op. cit.*, 1978.
128 Peter D. GRÜNWALD, Jay INJAE MYUNG and Mark A. PITT, *op. cit.*, 2005, p. 5.

According to the insight on which MDL is based, if we want to select a model for the description of a given piece of music, then we should focus on the identification of « regularities » in the piece. However, in the context of music and music cognition, the notion of « regularity » is highly connoted, and may refer to a completely different concept[129]. Therefore, we prefer to use the notion of « redundancy », which, in our particular practical case, is equivalent to regularity[130].

In the case of a systemic model[131], high redundancy between two units x_1 and x_2 implies that if we write the relation between the two units as $x_2 = f(x_1)$, then f will be short (simple), and the description of the two units as $\{x_1, f(x_1)\}$ will be shorter (simpler) than their literal description $\{x_1, x_2\}$[132].

The conclusion can be expressed as follows: in front of a large set of music examples that we want to describe, then we might want to select a limited number of models. If the models are systemic, then we want to pick the model that generally results into simple / short relations. The present Subsection is schematically summarized in **Figure 17.**

129 See for instance Edward W. LARGE and Caroline PALMER, « Perceiving temporal regularity in music », *Cognitive Science*, XXVI (2002), p. 1-37.

130 Regularity in the use of a given musical unit objectively results into redundancy, and redundancy can't exist without regularity in the use of at least one musical unit. In a context linked to mathematics, « redundancy » would conversely be highly connoted. This is not the case in music.

131 I.e. « a model based on units linked together by a number of relations » as seen during the **Introduction** and as translated from Jean LADRIÈRE, *op. cit.*, *Encyclopædia Universalis en ligne*.

132 An extreme case is met when $x_1 = x_2$, in which there is perfect redundancy between the two units, and writing $\{x_1, f(x_1)\}$ is almost twice shorter (simpler) as writing the literal $\{x_1, x_2\}$.

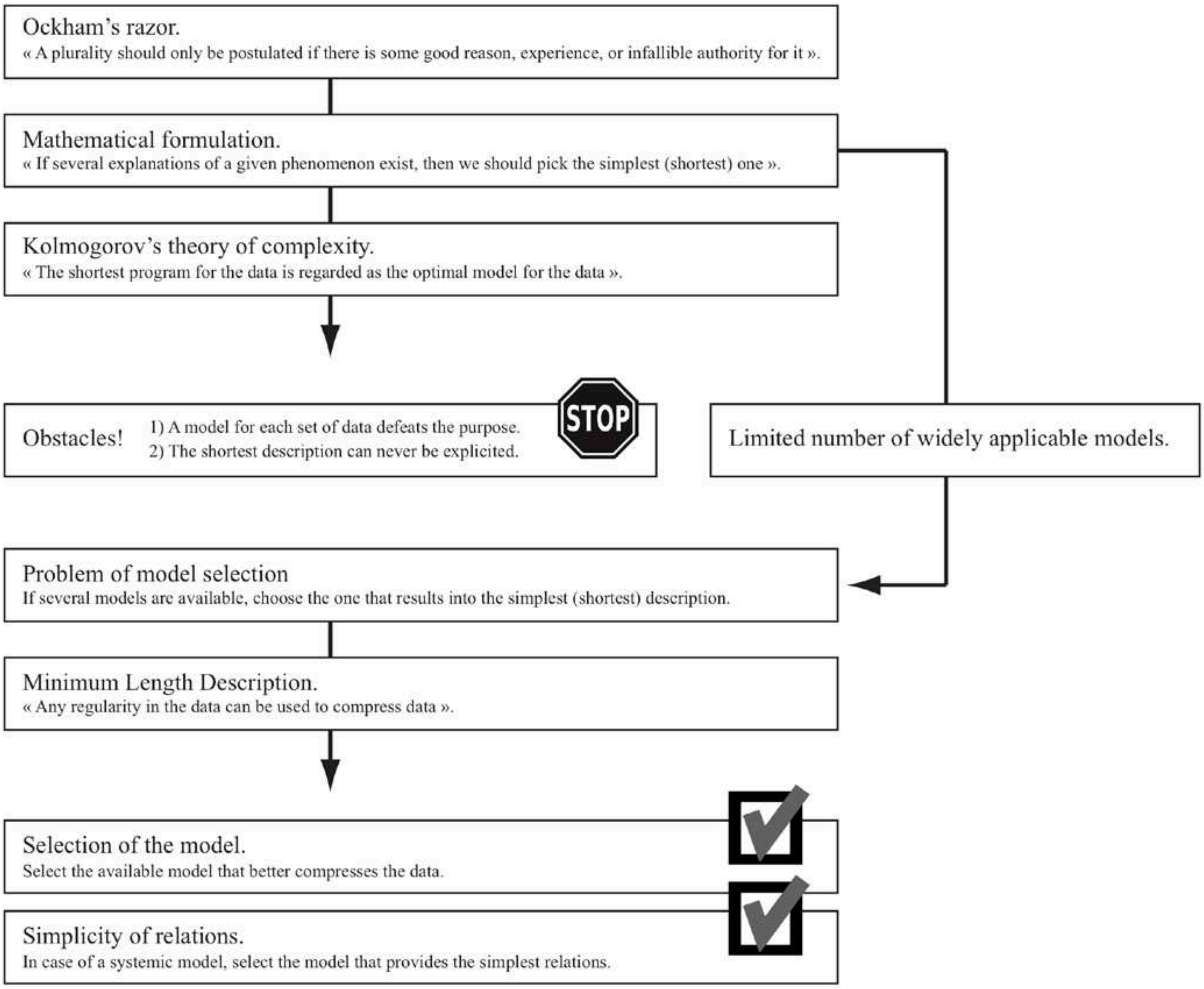

Figure 17. Schematic representation of the chain of reasoning that takes Ockham's razor principle of simplicity as a hypothesis, considers the necessity of models, and eventually provides usable guidelines for model selection.

Chapter III, Section 2: Application of the MDL principle.

We consider the description of the example shown on **Figure 18**, using the S&C model in its square form. Viewed in regard to X_{00}, morphological unit X_{10} is highly redundant. Elements highlighted in dark grey are a repetition of elements found in X_{00}, while elements highlighted in light grey can easily be derived from their counterpart in X_{00}[133].

Expressed formally, if $X_{10} = g(X_{00})$, then g is simpler (shorter) than X_{10}. Therefore, describing the example as $\{X_{00}, X_{01}, g(X_{00}), X_{11}\}$ is simpler (shorter) than describing it literally as $\{X_{00}, X_{01}, X_{10}, X_{11}\}$[134]. According to Ockham's razor mathematical formulation, this means that the description $\{X_{00}, X_{01}, g(X_{00}), X_{11}\}$ should be preferred over the literal description of the segment.

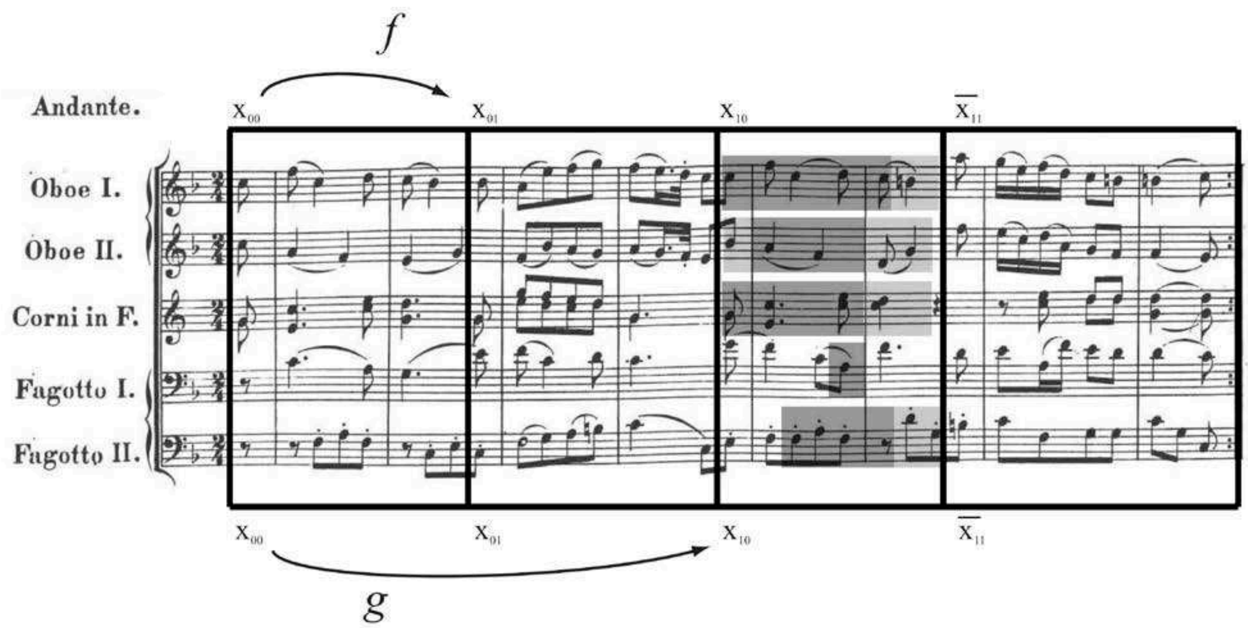

Figure 18. W.A. Mozart's « Divertimento Nr. 13 »[135], bars 1 to 8. In regard to X_{00}, unit X_{10} is highly redundant. This leads to a formulation of g that's simpler than the literal X_{10}.

133 For instance, the B natural at the end of unit X_{10}, « Oboe I » part, can easily be expressed as its counterpart in unit X_{00} transposed upward by one chromatic semitone.

134 This is equivalent to stating that $\{X_{00}, X_{01}, X_{10}, X_{11}\}$ has been compressed.

135 W.A. MOZART, « Divertimento Nr. 13 für 2 Oboen, 2 Hörner und 2 Fagotte in G-Dur. », K. 550, 1776, bars 1 to 8. Edition: *Wolfgang Amadeus Mozarts Werke, Serie IX: Cassationen, Serenaden und Divertimente*, Breitkopf & Härtel, 1880, p. 152-158.

A similar approach is considered for the example shown on **Figure 19**. In regard to x_{00}, unit x_{01} is highly redundant. The rhythm is the same, and the melodic profiles very similar. This means that the expression of f will be much shorter than the expression of x_{01}, and that $\{x_{00}, f(x_{00}), x_{10}, x_{11}\}$ will be shorter than $\{x_{00}, x_{01}, x_{10}, x_{11}\}$. Therefore, the former should be preferred over the latter.

On the example shown on **Figure 20**, the expressions of both f and g will be respectively shorter than the expressions of x_{01} and x_{10}. Therefore, $\{x_{00}, f(x_{00}), g(x_{10}), x_{11}\}$ should be picked over $\{x_{00}, x_{01}, x_{10}, x_{11}\}$. Notice how this approach may provide an answer to Nicolas Ruwet's objection to most methods of music analysis not formulating the discovery criteria on which they depend[136].

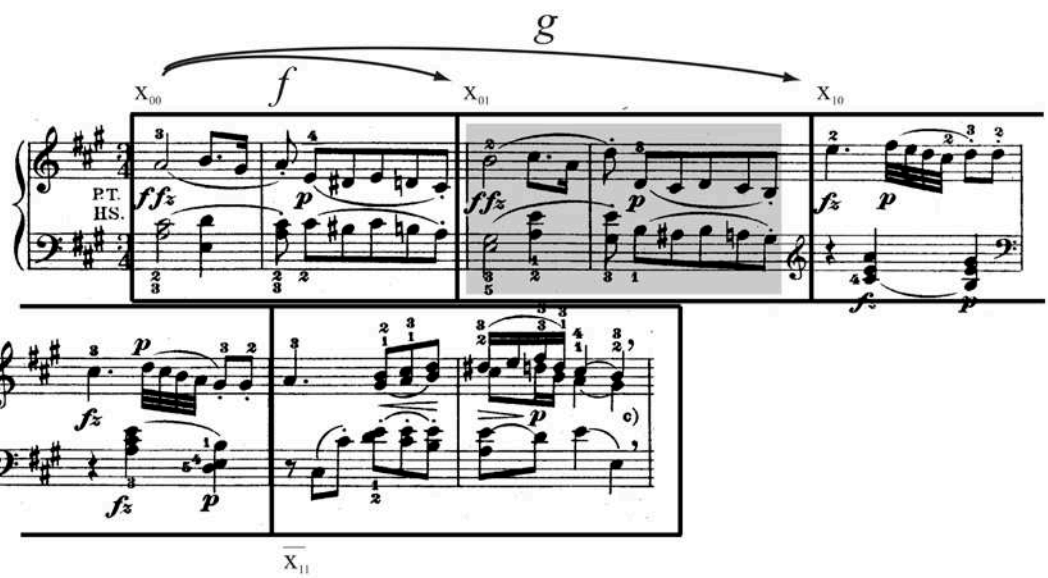

Figure 19. Rondeau from W.A. Mozart's sixth piano sonata, bars 1 to 8[137]. In regard to x_{00}, unit x_{01} is highly redundant. This leads to a formulation of f that's simpler than a formulation of x_{01}.

136 Nicolas RUWET and Mark EVERIST, *op. cit.*, 1987, p. 13.
137 W.A. MOZART, « Sonate Nr. 6 für das Pianoforte. » K. 284, 1775, « Rondeau en Polonaise », bars 1 to 8. Edition: Sigmund LEBERT and William SCHARFENBERG, *W.A. Mozart, Nineteen Sonatas for the Piano*, G. Schirmer, 1893, p. 222.

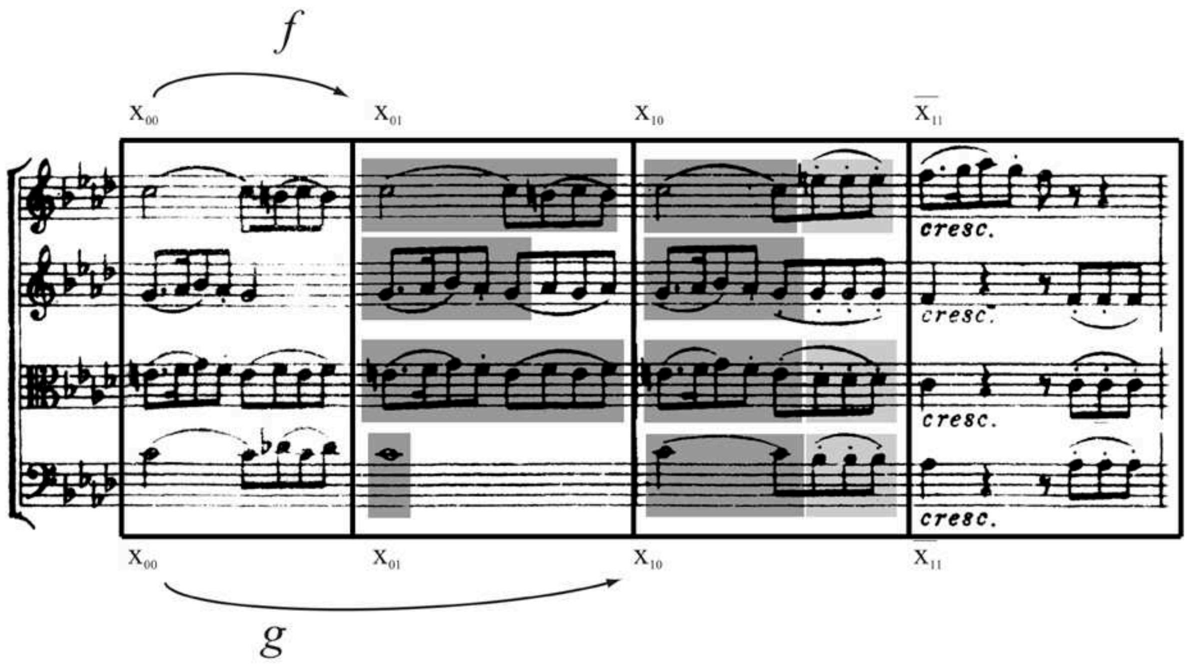

Figure 20. Bars 113-116 from F.J. Haydn's string quartet op. 20 n° 5[138]. In regard to X_{00}, units X_{01} and X_{10} are highly redundant. This leads to formulations of f and g that are respectively simpler (shorter) than formulations of X_{01} and X_{10}.

138 Franz J. HAYDN, « Streichquartett in F moll », op. 20, n° 5, Hob.III:35, 1771, bars 113-116. Edition: Wilhelm ALTMANN, Joseph Haydn String Quartets Op. 20 and 33, Complete, Ernst Eulenburg, 1930.

Chapter III, Section 3: Systemic and residual parts of a description.

In the present Section, we introduce the notion of a « residual » part of a description, in compliance to the principles mentioned in **Chapter III**, **Section 1**.

We focus on the example shown on **Figure 21**, which we describe using two consecutive instances of the S&C model. We focus on the « Kick »[139] part (bottom). Relation *g* from the first instance is close to the identity. It can be described using a number formulations, such as: « remove the third note », « remove the isolated eighth-note », or « remove the kick note that sounds lower than the others », the three formulations amounting to the same result in the present example[140].

On the other hand, relation g from the second instance is the identity, and links together two elements that are the same as the third element from the first instance. For such a description, we therefore use two different relations *g*, one for each segment. An alternative description for the first segment would consist in declaring the circled note as « extra-systemic », or « residual ». Such a description would result in $g = id.$, as is the case with the second segment.

Figure 22 compares the differences between the two descriptions, the first one without recourse to a residue, and the second one considering the circled note as residual. According to the hypothesis of simplicity to which we subscribe and as shown in **Chapter III, Section 1**, « if several explanations [...] of a given phenomenon [...] exist, then we should pick the [...] shortest [...] one »[141]. In the present case, it is clear that we should prefer the second description. This example introduces the possibility of a residual part to the description, for the determination of which we consider as non-systemic elements that are particularly not redundant[142].

The comparison between **Figure 23** and **Figure 24** provides another illustration for the notion of a description's residual content. While **Figure 23** is adapted from Universal Music Publishing's transcription of Franck Sinatra's « Strangers in the Night »[143], the transcription from **Figure 24** was made by the author. The difference between the two transcriptions is easily noticeable. While the transcription made by the author is more accurate, it can be observed that the transcription made by Universal Music Publishing has been stripped from all rhythmic elements that don't comply to a certain amount of regularity[144].

139 « Kick » stands for « kick drum », see GROVE MUSIC ONLINE, « Kick Drum », *Grove Music Online*, Oxford Music Online, Oxford University Press, http://www.oxfordmusiconline.com/subscriber/article/grove/music/52583 (accessed on July 24th, 2013).

140 All three formulations refer to the same note, which is circled in **Figure 21**.

141 Ming LI and Paul VITÁNYI, *op. cit.*, 2008.

142 This particular « kick » note is played only one time during the example. From a more general point of view, introduction of a residual part to a description is reminiscent of the reduction process leading from one layer to another in Schenkerian analysis, see Robert SNARRENBERG, « Heinrich Schenker », *Grove Music Online*, Oxford Music Online, Oxford University Press, http://www.oxfordmusiconline.com/subscriber/article/grove/music/24804 (accessed on August 13th, 2013).

143 Franck SINATRA, « Strangers in the Night », Reprise, 1966. Transcription copied from Franck SINATRA, *Strangers in the Night*, Universal Music Publ. Group / Hal Leonard Corp., 1966-2011, p. 2.

144 Using a term commonly encountered in audio production, we can say that Universal Music Publishing's transcription has been quantized to the eighth-note.

As seen in **Chapter III, Section 1**, in the light of the MDL principle, irregularities are non-redundant parts of the observed data that can't be used to provide a simple or compact description. According to this point of view, being stripped from irregularities, Universal Music Publishing's transcription is not so much a transcription than a description, a description that's compatible with the MDL principle, and, as a result, to Ockham's razor principle of simplicity. Actual audio content has been split into two layers:

1. The first layer amounts for the rhythmic irregularities. It is not shown on the published score.
2. The second layer is restricted to eighth notes. It is shown on the published score.

Figure 21. Two consecutive sections of Gojira's « Born in Winter »[145].

145 GOJIRA, « Born in Winter », *L'Enfant Sauvage*, Roadrunner, 2012, 1'50-2'05. Transcription made by the author.

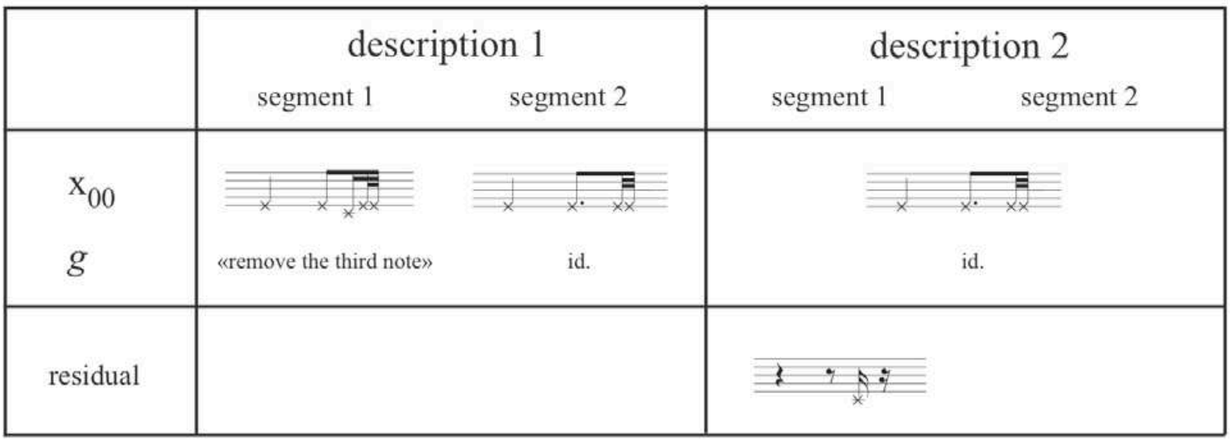

Figure 22. Introduction of a residual part of the description may lead to simpler descriptions.

Figure 23. Frank Sinatra's « Strangers in the Night » as published by Universal Music.

Figure 24. A more accurate transcription of Frank Sinatra's « Strangers in the Night »[146].

146 Franck SINATRA, « Strangers in the Night », Reprise, 1966, 0'12-0'53, Transcription made by the author.

Let's observe the second layer in terms of S&C model. This has been done in **Figure 16** from **Chapter II**, **Section 2**. Relations f and g are simple, based as they are on simple diatonic transpositions. Let's now try to describe the transcription from **Figure 23** in terms of S&C model. Both f and g will be extremely complicated.

We can conclude that Universal Music Publishing's description complies to the conclusions reached in **Chapter III, Section 1** in regards to systemic relations, according to which model selection for the description should be made on the basis of f and g being as simple as possible. Franck Sinatra's vocal part has been split into two layers, one being residual, and the other resulting in simple systemic relations. Only the systemic layer is shown on the published score.

While compatibility between this particular example of Universal Music Publishing's practices in terms of transcription and our interpretation of the MDL principle doesn't constitute a scientific proof, it provides a solid an attested illustration of the distinction we make between a simple « systemic » and a « residual » part in light of this interpretation.

CHAPTER IV:
THE S&C MODEL CLASS.

In this Chapter, we describe the S&C model class, of which the square form introduced in **Chapter II, Section 2** is a particular case.

Section 1 provides an overview of the S&C model class. **Section 2** combines the MDL principle with observation of redundancies at different time scales, in order to show that given a unique music excerpt, different descriptions based on the square S&C model can be found to be compliant with the principle of simplicity as seen in **Chapter III, Section 1**. While **Section 3** provides an overview of a cubic S&C model, **Section 4** focuses on a hypercubic S&C model. **Section 5** considers S&C models based on a number of units that's not a multiple of 4. Finally, **Section 6** suggests an interpretation of the S&C model class. While **Chapter III, Section 1** provides a theoretical framework for a selection between models that provide the simplest description of a musical piece of excerpt, it is not inside the scope of this work to provide definitive arguments that would make it possible to select between models from the S&C class. We plan to deal with this particular aspect in the context of our future PhD.

Chapter IV, Section 1: Overview of the S&C model class.

Members of the S&C model class share a number of common properties. They're systems of relations linking together morphological units, with, as a result, the projection of implications onto later morphological units. Projection of such implications is based on the fundamental hypothesis underlying the square S&C model[147]. A 8-bar semiotic segment may be described using several square S&C systems, including, for instance, a square S&C model encompassing bars 1, 2, 5, and 6. As a result, bar 6 will be the subject of an implication projected by bars 1, 2 and 5. Any given member of the S&C model class consists in a composition of the square S&C models one can observe between the morphological units it's based on.

147 As quoted from **Chapter II**, **Section 2**: « Given a set of four consecutive units, the first three units project an implication onto the fourth unit. This implication is realized when {unit 4 is to unit 3 what unit 2 is to unit 1} and {unit 4 is to unit 2 what unit 3 is to unit 1}. Conversely, it is denied when {unit 4 is not to unit 3 what unit 2 is to unit 1} or {unit 4 is not to unit 2 what unit 3 is to unit 1}. »

That said, given a particular model, observation of such square S&C models is not made between any or all morphological units. In **Chapter IV**, **Section 3** for instance, we will consider an 8-unit model in which units 1, 2, 5, and 6 are described using a square S&C model, but units 1, 2, 4 and 5 for instance are not. Focus on specific combinations of square S&C models implies the hypothesis according to which these particular models are better suited to the description of music excerpts[148]. The 8-unit system model we consider in **Chapter IV**, **Section 3** relies on square S&C models that can be represented as the faces of a cube. The 16-unit model we focus on in **Chapter IV, Section 4**, is based on the square S&C models that can be represented as the faces of a 4-dimension hypercube.

Description using a member of the S&C model class always results into two types of morphological units. The first type concerns units on which the implication stands, we call them « carrier units »[149]. Amongst the carrier units, the first one possesses a particular status, and is called the « primer »[150]. Relations between the carrier elements create implications onto other units, which become potentially contrastive and belong to the second type, which of « potentially contrastive units ». By definition, an entirely non-contrastive state of the system can be inferred from the carrier elements. Such a state is called the « carrier » state or « carrier » for short. The contrast(s) are considered as logical modulations of the carrier[151].

148 « Better suited », as understood in **Chapter III, Section 1:** models that result into a higher compression ratio, which means they're based on relations that can be expressed simply, i.e. linking couple of elements that exhibit a high degree of redundancy.

149 In the case of the square S&C model, the carrier elements are unit x_{00}, x_{01} and x_{10}.

150 In the case of the square S&C model, all morphological units from the system are expressed in relation to x_{00}. This is shown in **Chapter II, Section 2**, in which it is explained that the square S&C model can be written as $\{x_{00}, f(x_{00}), g(x_{00}), \gamma\}$, where $\gamma = k(f \circ g)^{-1}$ and $x_{11} = k(x_{00})$.

151 In the field of electronic engineering and telecommunications, the concept of modulation is commonly defined as the process of varying one or more properties of a known carrier signal (usually a periodic waveform) with an unknown modulating signal conveying information that fluctuates at a lower frequency than that of the carrier. For more details on the contrast as a digital modulation, see Frédéric BIMBOT & al., « System & Contrast: A Polymorphous Model Of The Inner Organization Of Structural Segments Within Music Pieces », *op. cit.*

Chapter IV, Section 2:
Change of time scale and resulting possible descriptions.

Figure 25 suggests three possible descriptions of the example shown in **Figure 18** from **Chapter III, Section 1**. Each one of them follows the MDL principle according to which a description using a systemic model should take advantage of redundancy between morphological units in order to provide relations that are as simple as possible.

In **Figure 25, top**, redundancy between morphological units 1 and 3 result into a simple *f* relation[152]. In **Figure 25, middle**, we describe the same extract using not one instance of the square S&C model, but two. Strong redundancies can be observed between units 1 and 2 from the two instances[153]. Such a change in the scale of observation results into the extract being divided into eight units instead of four. In **Figure 25, bottom**, we describe the same extract using the same eight units, this time grouped into a single system of relations. Strong redundancies can be observed between the following couples of units: { 1, 2 }, { 5, 6 }, { 1, 5 }, and { 2, 6 }. Given the scale of observation, this eight-unit system of relations is compliant with the MDL principle[154].

As illustrated on **Figure 26**, similar observations can be made about Britney Spears' « Radar »[155]. The example consists in a single semiotic unit as defined in **Chapter I, Section 2**. Similarly to the example shown in **Figure 25**, it can be described using a single instance of the S&C model's square form (« description 1 »), two consecutive instances of the S&C model's square form (« description 2 »), or a single instance of an eight-unit model (« description 3 »). In case of description 1, redundancies between morphological units 1, 2 and 3 result into simple *f* and *g* relations. In case of description 2, first instance, redundancies between units 1, 2 and 3 result into simple *f* and *g* relations. In case of description 2, second instance, redundancies between units 1 and 2 result into a simple *f* relation. In case of description 3, redundancies between several couples of units result into a number of simple relations.

All such descriptions are variants of the square S&C model, while being compliant to the initial principle of simplicity. We will now suggest standardized forms of such variants, resulting into the definition of the S&C class of models.

152 Resulting into a « period-like » form, see **Chapter I, Section 3**.
153 Resulting into two « sentence-like » forms, see **Chapter I, Section 3**.
154 « Compliant with the MDL principle », as seen in **Chapter III, Section 1**: such a description is liable to provide a high compression ratio, coming from the fact that the relations on which the system is based can be expressed simply, which means relations are based on couples of elements that exhibit a high degree of redundancy.
155 Britney SPEARS, « Radar, *Blackout*, Jive, 2007, 015-0'30. Transcription made by the author.

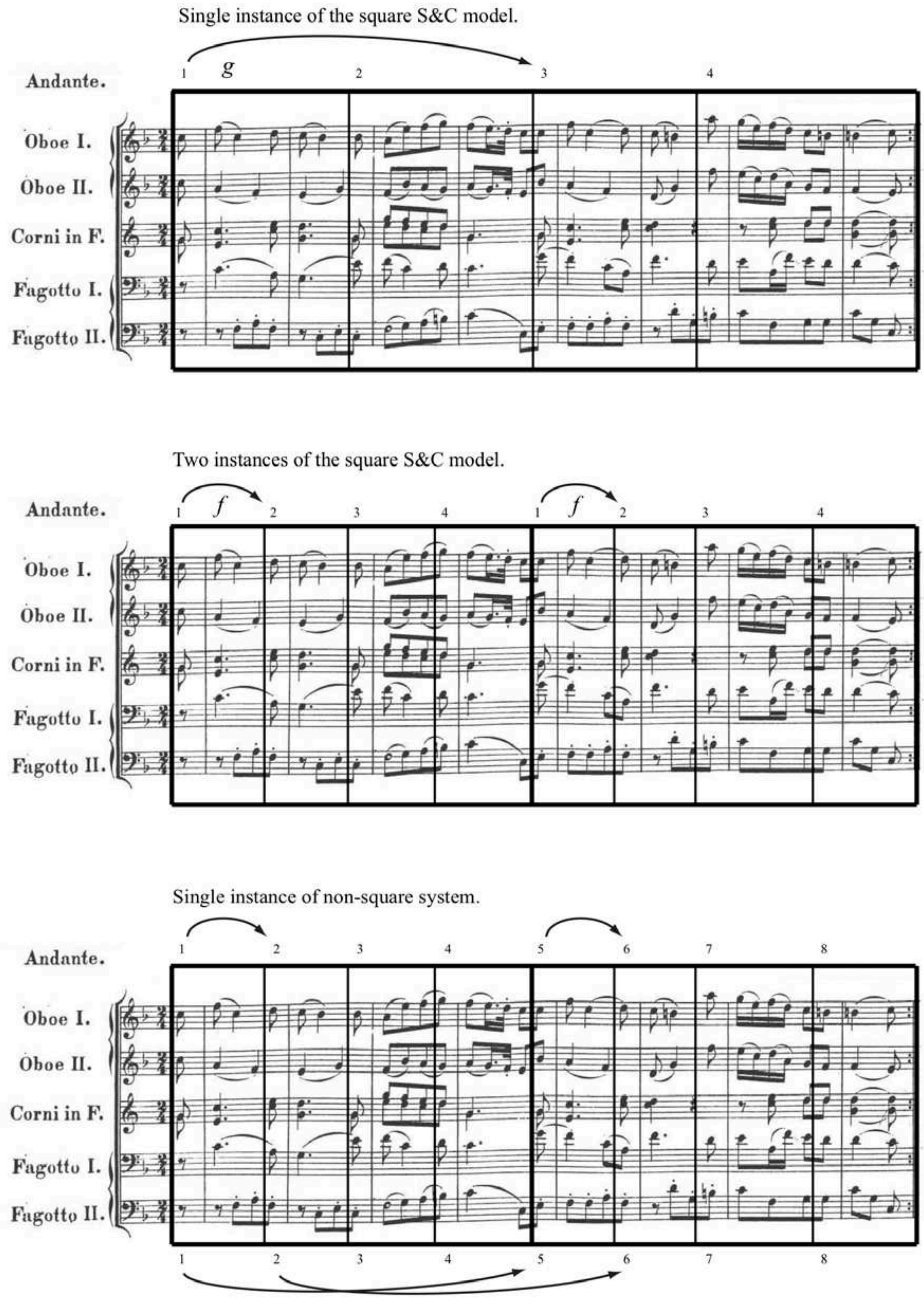

Figure 25. Based on the observation of redundancies, this excerpt from Mozart's « Divertimento » K. 550 may be described using different models or combinations of models[156].

156 W.A. MOZART, « Divertimento Nr. 13 für 2 Oboen, 2 Hörner und 2 Fagotte in G-Dur. », K. 550, 1776, bars 1 to 8. Edition: *op. cit.*, 1880.

Figure 26. Based on the observation of redundancies, this excerpt from Britney Spears'« Radar » may also be described using the same models or combinations of models[157].

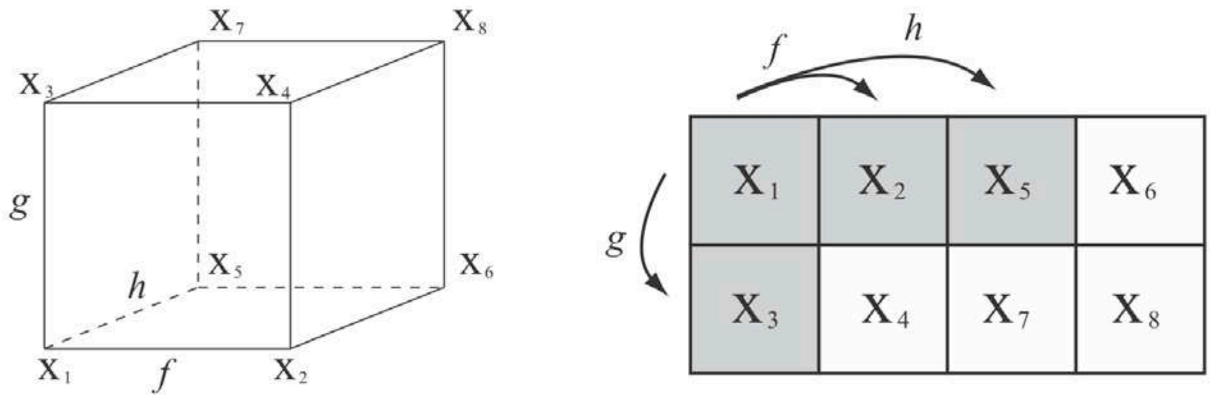

Figure 27. Two schematic representations of the cubic S&C model. On the left, a three-dimensional representation. On the right, a « flat » representation.

157 Britney SPEARS, « Radar », *op. cit.*, 2007, 015-0'30.

Chapter IV, Section 3: The cubic S&C model.

Both observation of the example shown in **Figure 25, bottom** and observation of the example shown on **Figure 26** suggest that a model based on eight morphological units is not in contradiction with the MDL principle and the initial principle of simplicity. In this Section, we describe a particular 8-unit model called the cubic S&C model. Like all members of the S&C class of models, this model is based on the composition of several particular square S&C models. An exhaustive list illustrating the involved square S&C models, sorted by the position of their potentially contrastive unit, is given in **Figure 28** and **Figure 29**.

The three-dimensional representations provided on the left side are made in the form of a cube[158]. The list of all square S&C models that comply with the aforementioned constraints can be made according to the following process. Given any unit, one can find the square S&C model(s) of which this unit is the potential contrast by simply identifying each square of which the unit is the fourth element. The « flat » representation on the right side is a projection of the cube that possesses the advantage of being much more easily drawn, even though it is less accurate.

Considering all the systems shown on **Figure 28** and **Figure 29**, one can observe four units that are never subject to implications (x_1, x_2, x_3, x_5), along with four potentially contrastive units (x_4, x_6, x_7, x_8). As a result, the carrier for this model can be entirely described using four elements. Making explicit the relations between the carrier units, this results into the expression of the model as $\{x_1, f, g, h\}$, a synthetic representation of which is illustrated on **Figure 27**.

The present model possesses interesting properties. In the context of a period-like form for instance, h is close to the identity, and $x_6 = f(x_5)$, which makes x_6 non-contrastive. In the case of a sentence-like form, g is close to the identity or at least very simple, and $x_4 = f(x_3)$, which makes x_7 non-contrastive[159]. The cubic S&C model therefore encapsulates both period and sentence forms, as does the square S&C model.

158 We represent the 4-element S&C model as a square. It is only natural that we should represent the 8-element S&C model as a cube. Vertices, edges and faces respectively represent morphological units, relations between units, and a square S&C model

159 In both cases, this contributes into making the description as a cubic model simpler than the literal description, which is, according to **Chapter III, Section 1**, the goal we're pursuing.

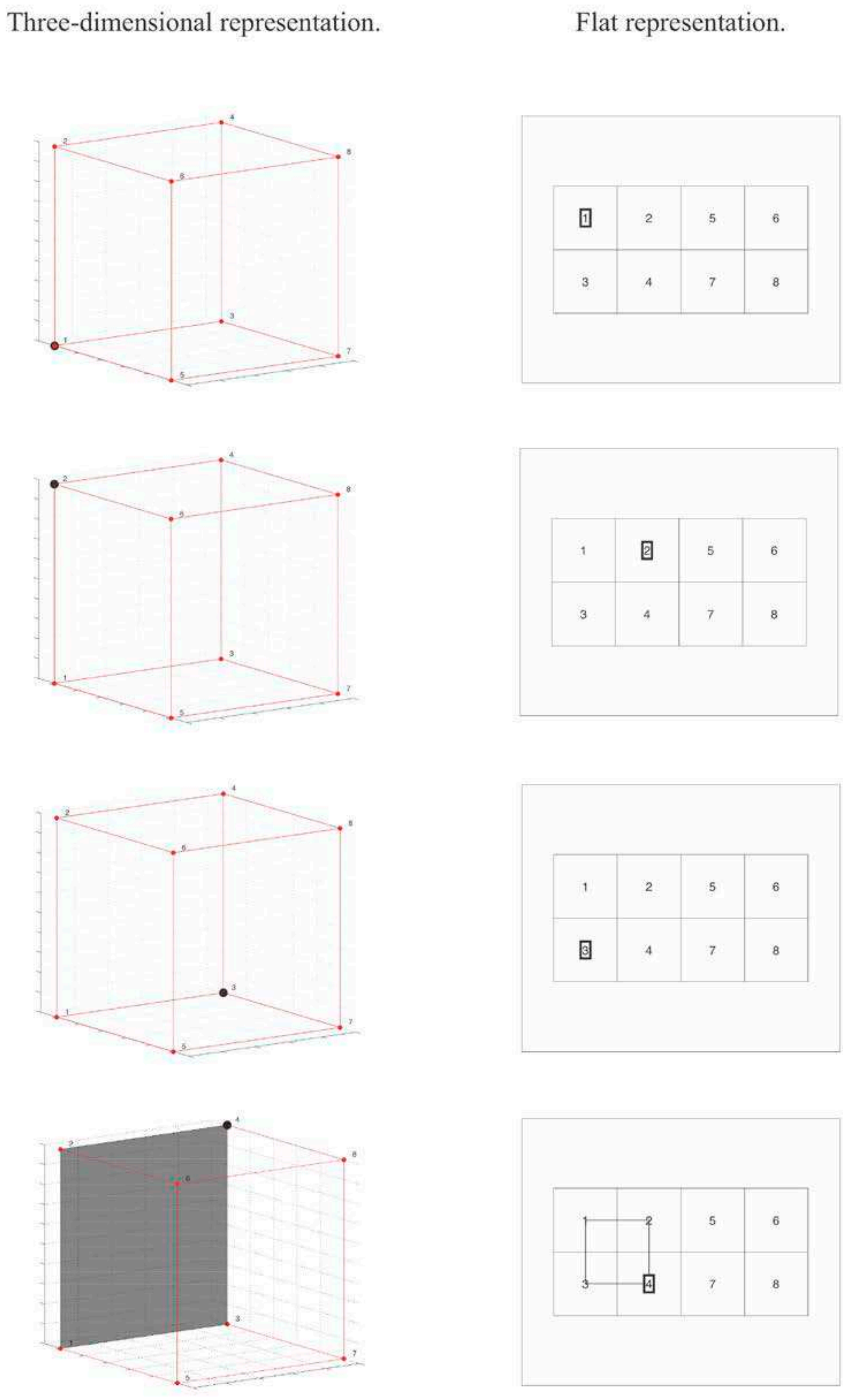

Figure 28. Cubic system, morphological units 1 through 4. Units 1, 2 and 3 are carrier units, unit 4 is the contrast position of one system.

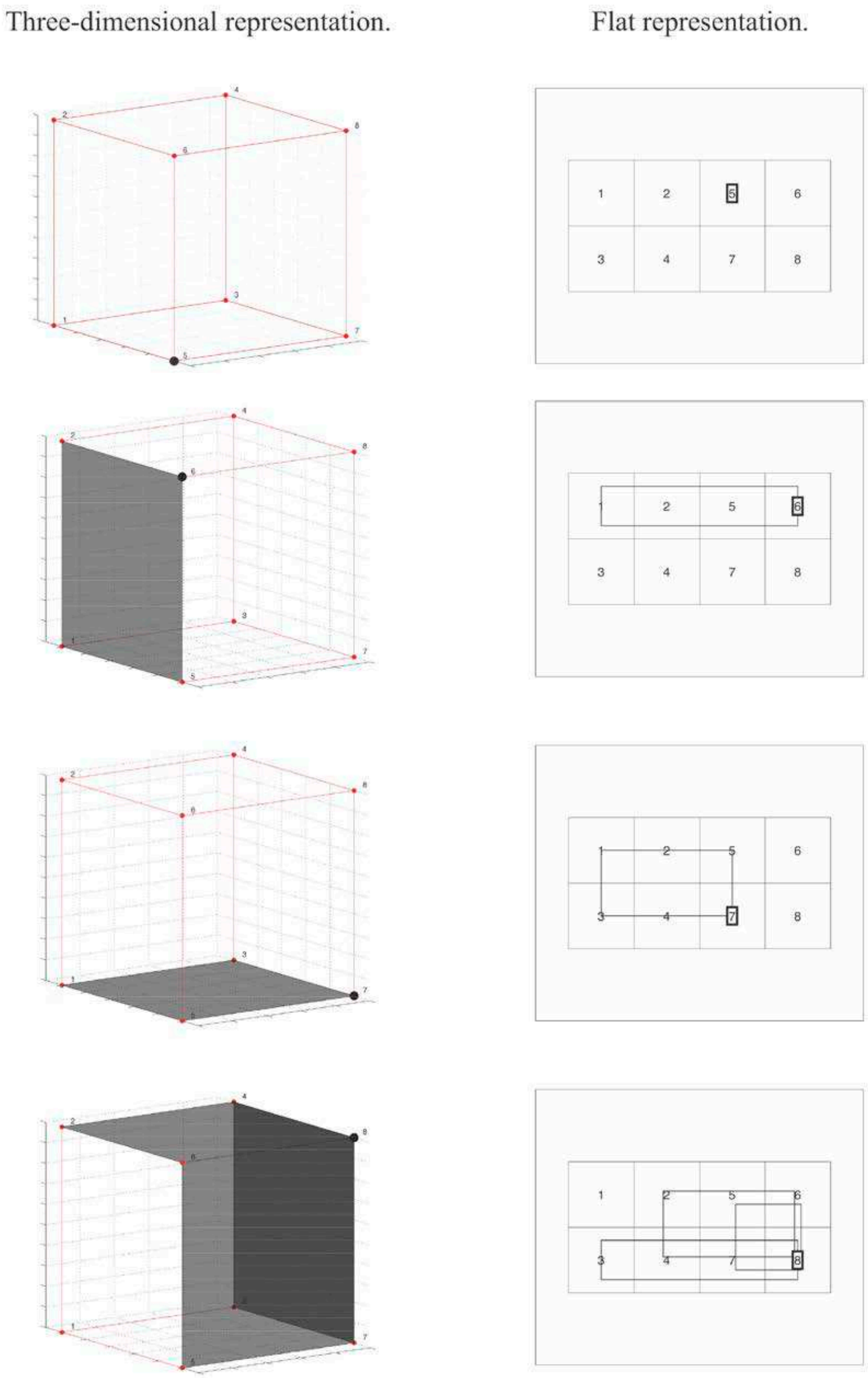

Figure 29. Cubic system, morphological units 5 through 8. Unit 5 is a carrier unit, units 6 and 7 are contrast positions to one system. Unit 8 is the contrast position to three systems

An important particularity of morphological unit X_8 is that it is the subject of three simultaneous implications, which can sometimes be observed to conflict[160]. An example of conflicting implications is illustrated on **Figure 30**, in which the implied x_8 are represented in gray. The implications may converge, such as in the case of the « hi-hat » track, but they mostly conflict.

We want to resolve the conflict. In case of conflicting implications, we can compare each one of the systems to which the implications belong. In light of the MDL principle, the systems can be considered as competing models. As seen in **Chapter III, Section 1**, when confronted to a problem of model selection, then we want to choose the simplest one. We have three systems to compare. We may do so by considering x_8 as a whole, or we may consider the conflicting implications track by track. We choose to resolve the implications track by track. As detailed in the **Appendix**, we reach the following conclusions:

- « Kick »[161] track: system $\{x_2, x_4, x_6, x_8\}$is preferred.
- « Snare »[162] track: system $\{x_2, x_4, x_6, x_8\}$ is preferred.
- « Rim »[163] track: system $\{x_3, x_4, x_7, x_8\}$ is preferred.
- « Hi-hat »[164] track: all implications converge.
- « Key »[165] track: system $\{x_5, x_6, x_7, x_8\}$ is preferred.
- « Hi Pad »[166] part: all implications converge.

As seen in **Chapter II, Section 1**, our approach follows Narmour's temporary dismissal of the difference between the perceptual and logical contexts. The present method for choosing between conflicting implications highlights the value of such a dismissal, without which it wouldn't have been possible.

160 Simultaneous and potentially conflicting implications are not specific to the S&C model. A similar remark concerning conflicting « expectations » are mentioned in *Explaining Music: Essays and Explorations*, University of California Press, 1977, as cited in Naomi CUMMING, *op. cit.*, 1992, p. 356. Eugene Narmour also mentions « the question of multiples rules » in Eugene NARMOUR, *op. cit.*, 2000, p. 393.

161 « Kick » stands for « kick drum », see GROVE MUSIC ONLINE, « Kick Drum », *op. cit.*

162 « Snare » stands for « snare drum », see GROVE MUSIC ONLINE, « Snare Drum », *Grove Music Online*, Oxford Music Online, Oxford University Press, http://www.oxfordmusiconline.com/subscriber/article/grove/music/26043 (accessed on July 24th, 2013).

163 « Rim » stands for « rim shot », see GROVE MUSIC ONLINE, « Rim Shot », *Grove Music Online*, Oxford Music Online, Oxford University Press, http://www.oxfordmusiconline.com/subscriber/article/grove/music/23479 (accessed on July 24th, 2013).

164 GROVE MUSIC ONLINE, « Hi-hat », *Grove Music Online*, Oxford Music Online, Oxford University Press, http://www.oxfordmusiconline.com/subscriber/article/grove/music/52537 (accessed on July 24th, 2013).

165 « Key » stands for « Keyboard(s) ».

166 « Hi Pad » stands for « high synth pad », a « pad » being a slow-attack, sustained synthesizer sound. See Mike SENIOR, « Creating & Using Synth Pad Sounds », *Sound on Sound* (May 2010).

Similarly to what is observed in **Chapter IV, Section 3** concerning the cubic model, the hypercubic model encapsulates both sentence- and period-like forms. In the case of a period-like form, g_2 is close to the identity, with X_{10}, X_{11} and X_{12} being non-contrastive at least in regard to specific implications[167]. In the case of a sentence-like form, f_2 is very simple, with X_6, X_7 and X_8 being generally non-contrastive[168].

Considering all the systems shown on **Figures 33 through Figure 36**, one can observe five units which are never subject to implications $(x_1, x_2, x_3, x_5, x_9)$, along with eleven potentially contrastive units (all the other units). As a result, the carrier state of this model can be entirely described using five elements. Making explicit the relations between the carrier units, this results into the expression of the model as $\{x_1, f_1, f_2, g_1, g_2\}$, a synthetic representation of which is illustrated on **Figure 31**.

Chapter IV, Section 4: The hypercubic S&C model.

Let's consider **Figure 32**, and focus on the three tracks noted as « S.1 », « S.2 » and « S.A. »[169]. We observe that units 1, 5, 9 and 13 are identical. Therefore, description of these four units is simpler if considered as a square S&C model. The same observation applies to units 2, 6, 10 and 14. Similarly, description of units $\{x_3, x_7, x_{11}, x_{15}\}$ and $\{x_4, x_8, x_{12}, x_{16}\}$ is simpler if considered as a contrastive square S&C model. This suggests that in this case, a model based on sixteen morphological units is not in contradiction with the MDL principle.

In this Section, we describe a particular 16-unit model called the hypercubic S&C model. Like all members of the S&C class of models, this model is based on the composition of several particular square S&C models. An exhaustive list illustrating the involved square S&C models, sorted by the position of their potentially contrastive unit, is given in **Figure 34 through Figure 37**. The three-dimensional representations provided on the left side are made in the form of a tesseract[170]. Vertices, edges and faces respectively represent morphological units, relations between units, and square S&C models[171].

167 In the case of the example from **Figure 9** from **Chapter II, Section 2**, X_4 is contrastive. So is X_{12} in regard to $\{x_9, x_{10}, x_{11}, x_{12}\}$. However, X_{12} is non-contrastive in regard to $\{x_3, x_4, x_{11}, x_{12}\}$.

168 In the case of the example from **Figure 10** from **Chapter II, Section 2**, X_4 is contrastive. So is X_8 in regard to $\{x_5, x_6, x_7, x_8\}$. However, X_8 is non-contrastive in regard to $\{x_3, x_4, x_7, x_8\}$.

169 These tracks consist in three components of a complex synthesizer part.

170 We represent the 4-element S&C model as a square (a two-dimension hypercube), and the 8-element S&C model as a cube (a three-dimension hypercube). The 16-element S&C model is therefore represented as a four-dimension hypercube, also called a « tesseract ». See Eric WEISSTEIN, « Hypercube », *MathWorld – A Wolfram Web Resource*, http://mathworld.wolfram.com/Hypercube.html (accessed on July 23rd, 2013). Although the proper way to refer to a 16-element system would therefore be as a « tesseractic » system, we consider the generic denomination as a « hypercubic » system to be slightly less fearful.

171 A tesseract is made from 24 faces. Therefore, 24 square S&C models can be observed in a hypercubic S&C model.

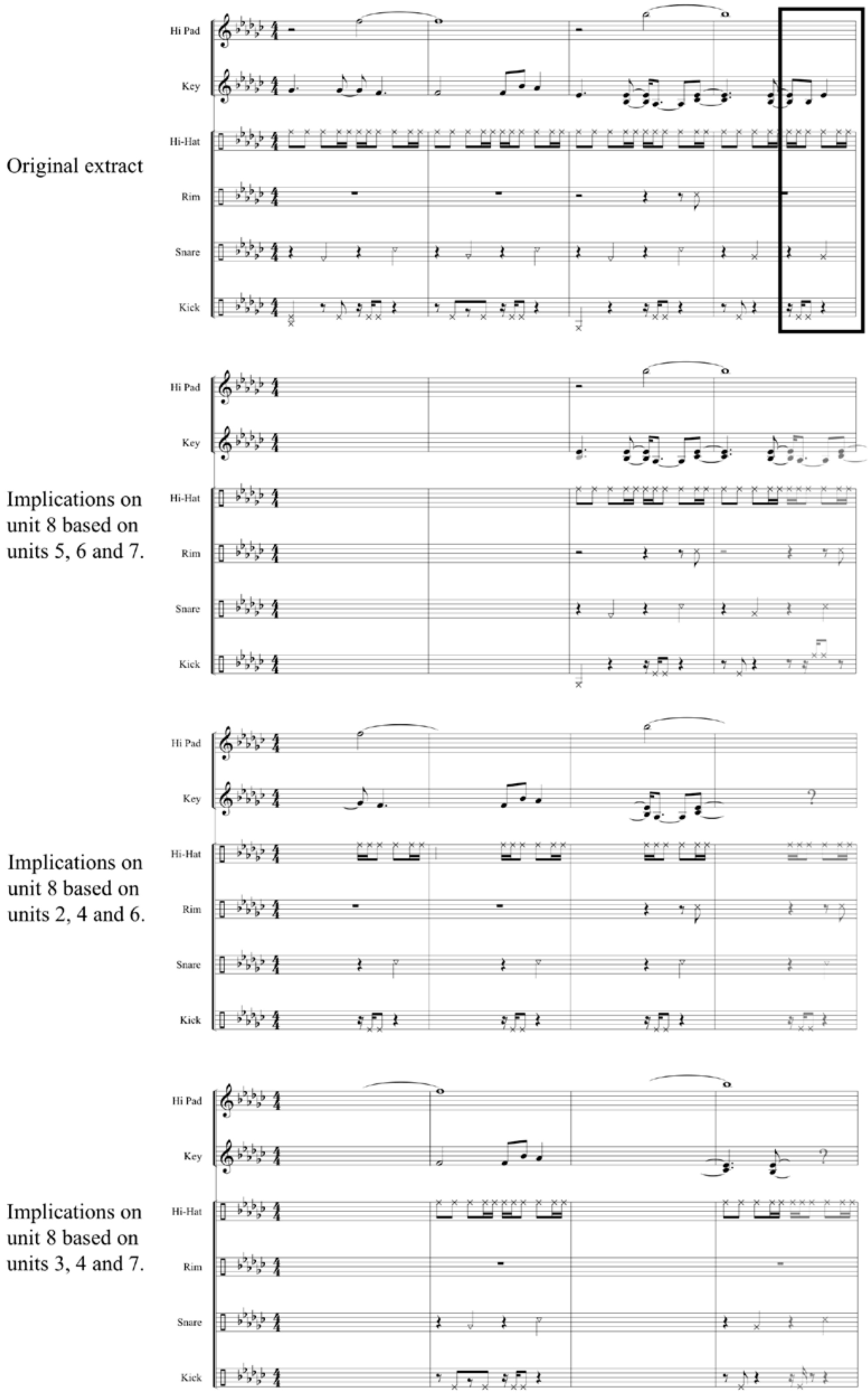

Figure 30. Conflicting implications projected on unit 8 in Aphex Twin's « IZ-US »[172].

172 APHEX TWIN, « IZ-US », *Come to Daddy EP*, Warp, 1997, 1'41-1'49. Transcription made by the author. Triangle note-heads in the snare part indicate a reverberated snare.

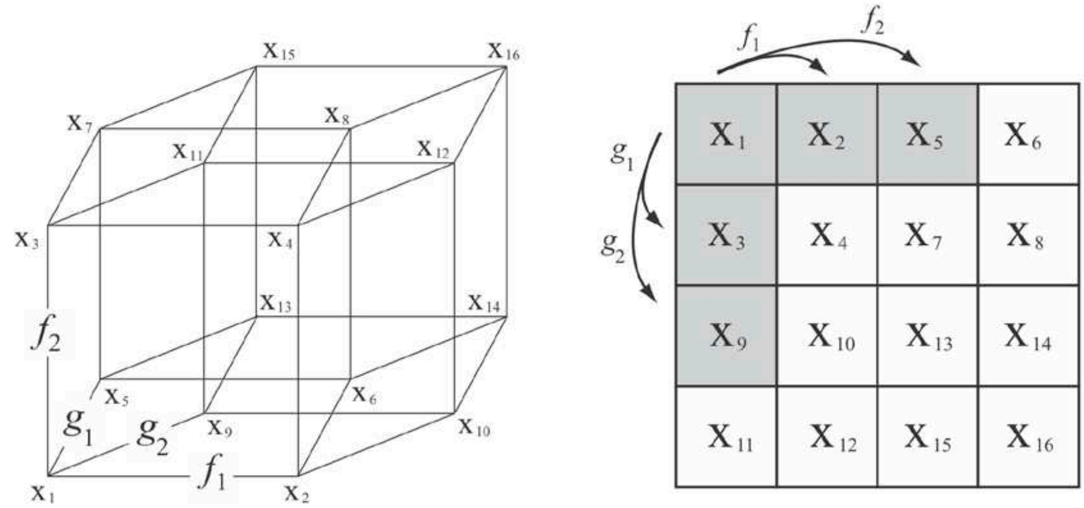

Figure 31. Two schematic representations of the hypercubic S&C model. On the left, a pseudo three-dimensional representation. On the right, a « flat » representation.

Five units from the hypercubic S&C model are concerned with projections of potentially conflicting implications. These are:

- Unit 8, which is the fourth element of systems $\{x_2, x_4, x_6, x_8\}$, $\{x_3, x_4, x_7, x_8\}$, and $\{x_5, x_6, x_7, x_8\}$
- Unit 12, the fourth element of systems $\{x_2, x_4, x_{10}, x_{12}\}$, $\{x_3, x_4, x_{11}, x_{12}\}$, and $\{x_9, x_{10}, x_{11}, x_{12}\}$.
- Unit 14, the fourth element of systems $\{x_2, x_6, x_{10}, x_{14}\}$, $\{x_5, x_6, x_{13}, x_{14}\}$, and $\{x_9, x_{10}, x_{13}, x_{14}\}$.
- Unit 15, the fourth element of systems $\{x_3, x_7, x_{11}, x_{15}\}$, $\{x_5, x_7, x_{13}, x_{15}\}$, and $\{x_9, x_{11}, x_{13}, x_{15}\}$.
- Unit 16, the fourth element of systems $\{x_4, x_8, x_{12}, x_{16}\}$, $\{x_6, x_8, x_{14}, x_{16}\}$, $\{x_7, x_8, x_{15}, x_{16}\}$, $\{x_{10}, x_{12}, x_{14}, x_{16}\}$, $\{x_{11}, x_{12}, x_{15}, x_{16}\}$, and $\{x_{13}, x_{14}, x_{15}, x_{16}\}$.

In the case of the example shown on **Figure 32**, conflicting implications can be observed. The **Appendix** provide details and ways of addressing conflict resolution, in which we conclude that in the particular case of this semiotic segment:

- x_8 should be described as the fourth unit of either $\{x_2, x_4, x_6, x_8\}$ or $\{x_3, x_4, x_7, x_8\}$.
- x_{12} should be described as the fourth unit of $\{x_2, x_4, x_{10}, x_{12}\}$ or $\{x_3, x_4, x_{11}, x_{12}\}$.
- x_{14} should be described as the fourth unit of $\{x_2, x_6, x_{10}, x_{14}\}$.
- x_{15} should be described as the fourth unit of $\{x_5, x_7, x_{13}, x_{15}\}$.
- x_{16} should be described as the fourth unit of $\{x_4, x_8, x_{12}, x_{16}\}$.

Selection of a single system in case of multiple implications results into entirely describing the hypercubic model with eleven systems, which is the number of non-carrier morphological units[173].

173 The 4-dimension hypercube contains twenty-four faces. Therefore, the hypercubic or « tesseractic » system is built from twenty-four square S&C models. Using the MDL principle, and considering simultaneous implications as competing models, each potentially contrastive unit is subject to only one implication. This is what is done in the **Appendix**, and it results into eleven systems only, each potentially contrastive unit being described as the contrast of only one system.

Figure 32. Description of the synthesizer part from Nine Inch Nails' « Ruiner (version) »[174] using a hypercubic model is compliant to the MDL principle.

174 NINE INCH NAILS, « Ruiner (version) », *Further Down the Spiral (UK release)*, Island, 1995, 0'01-0'17. Transcription made by the author. « S.1 » and « S.2 » stand for « Synthesizer 1 » and « Synthesizer 2 ». These two tracks contain a transcription of the harmonic content of a synthesizer part. « S.A. » stands for « Synthesizer's attack ». It contains a transcription of attack-type sounds that can be heard as either associated to « S.1 », to « S.2 », or as a separate part.

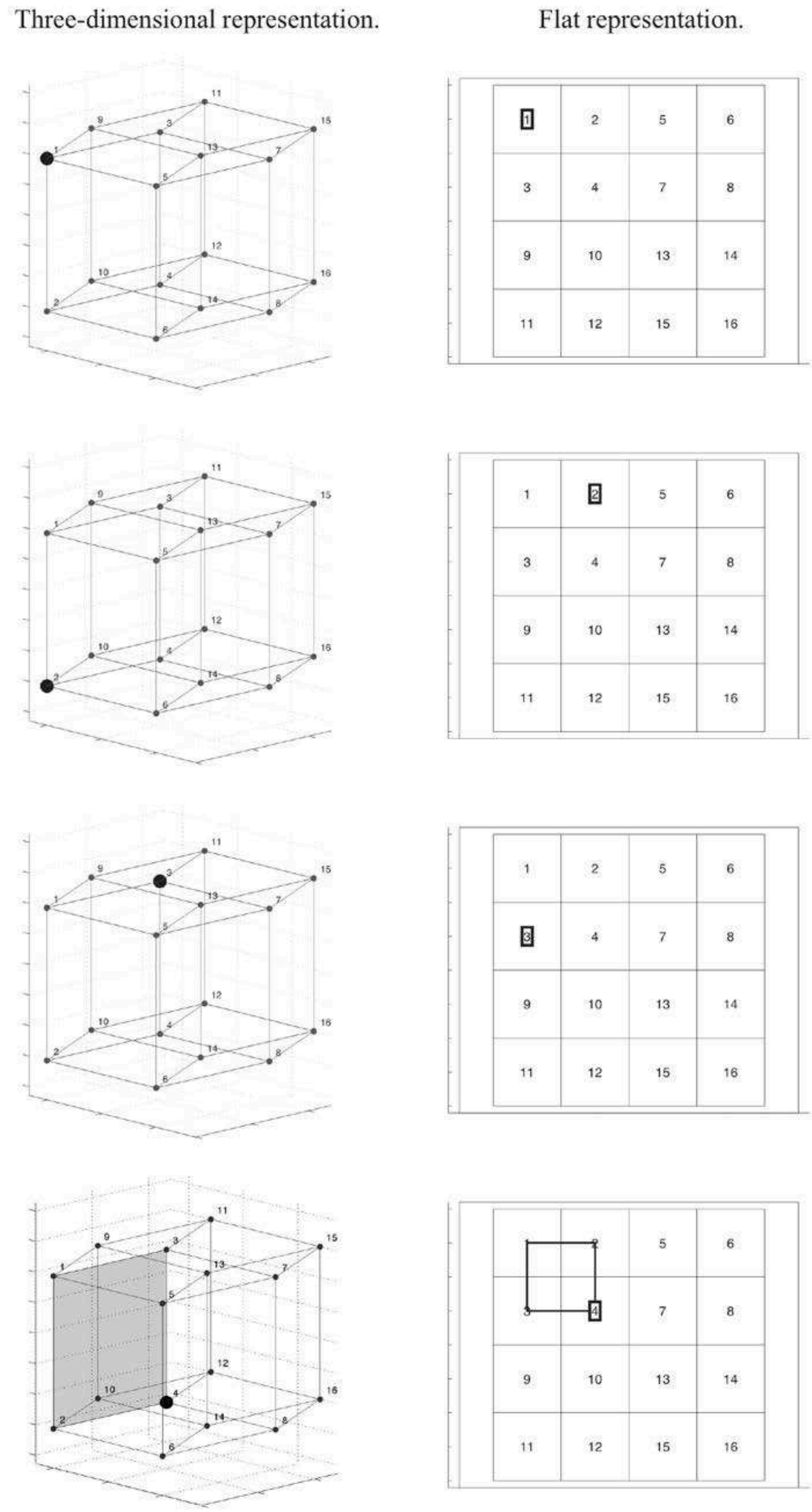

Figure 33. Hypercubic system, morphological units 1 through 4. Units 1, 2 and 3 are carrier units, unit 4 is the contrast position of one system.

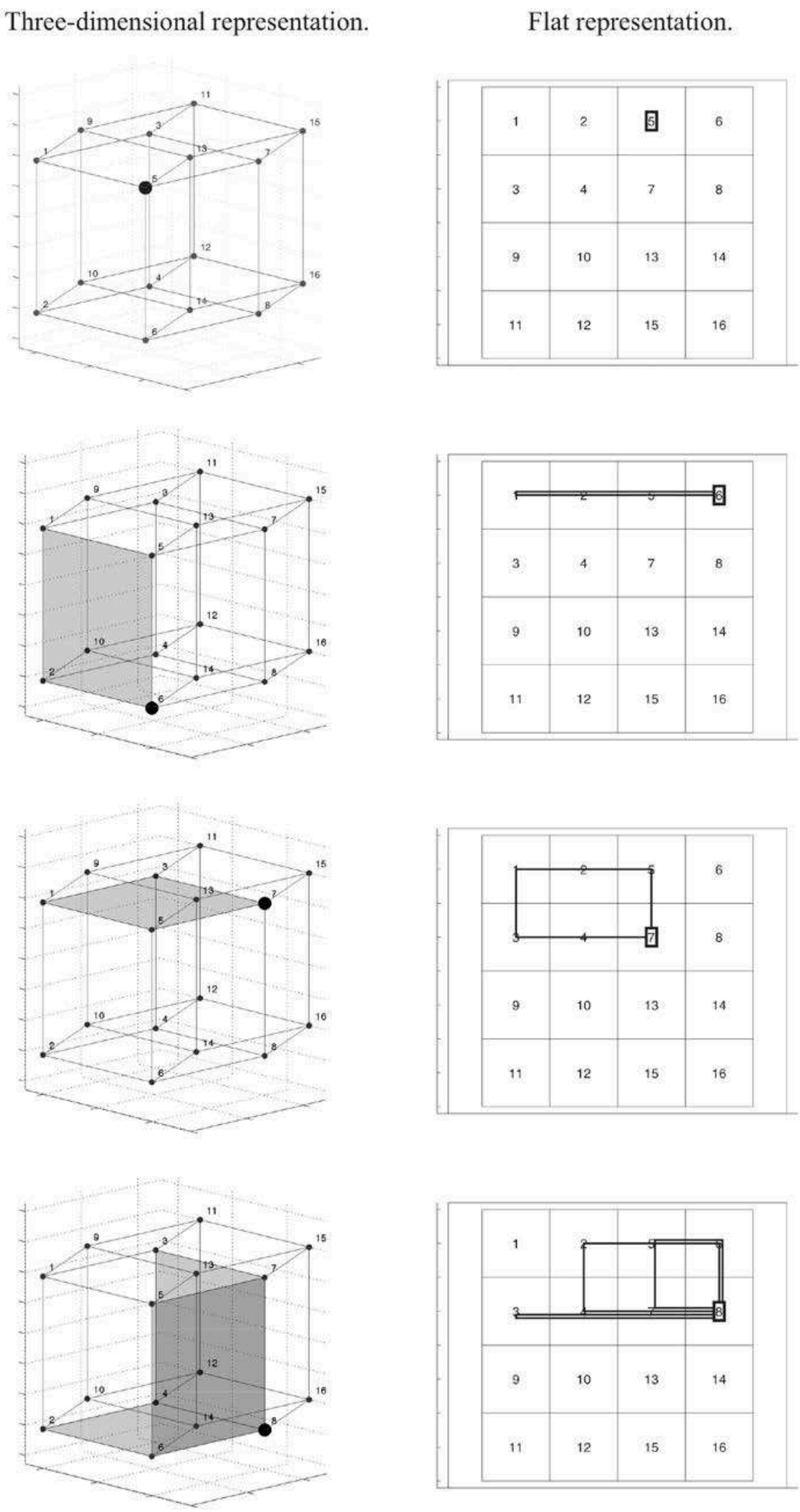

Figure 34. Hypercubic system, morphological units 5 through 8. Unit 5 is a carrier unit, units 6 and 7 are the contrast position of one system. Unit 8 is the contrast position of three systems.

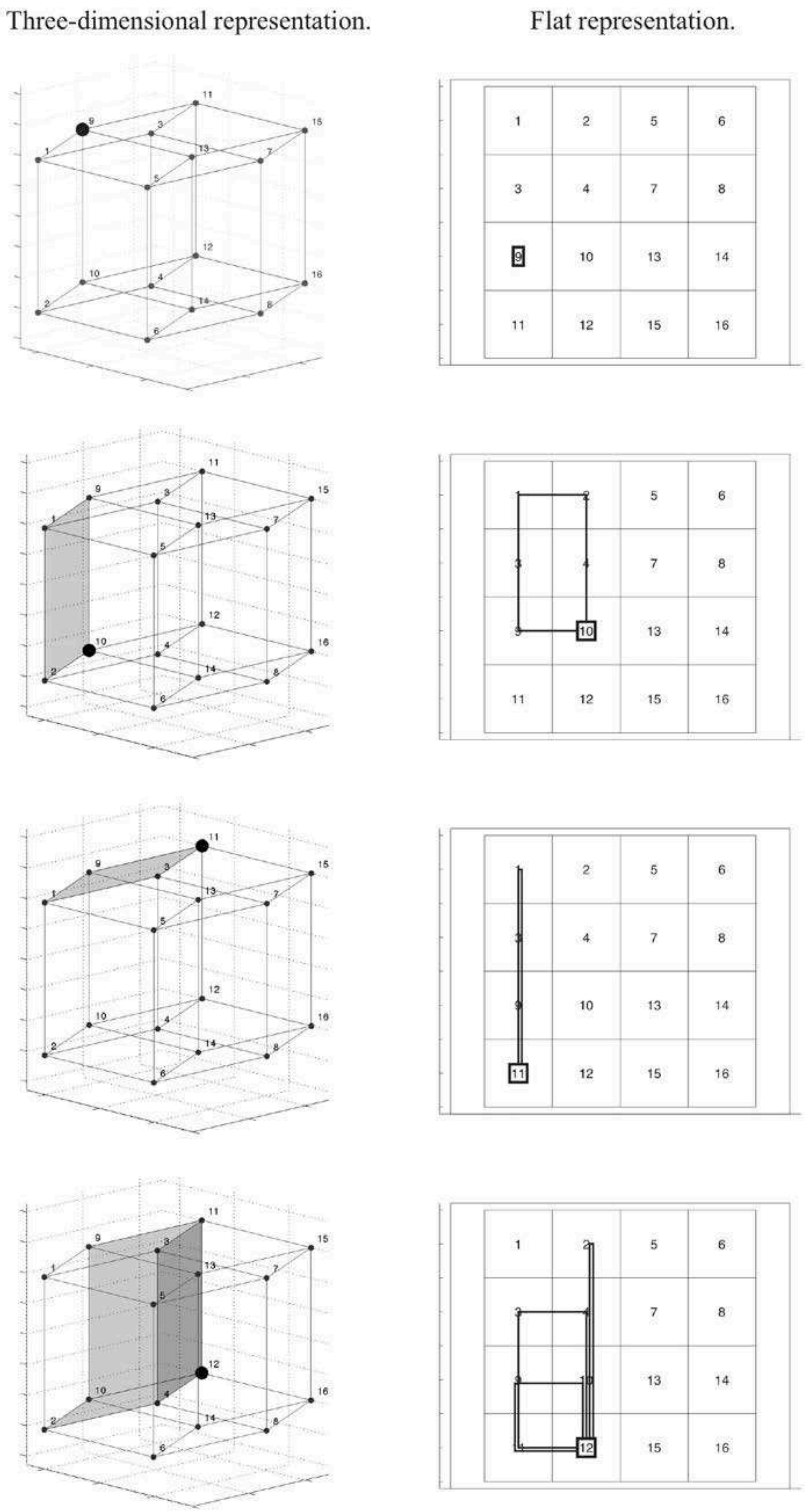

Figure 35. Hypercubic system, morphological units 9 through 12. Unit 9 is a carrier unit, units 10 and 11 are the contrast position of one system. Unit 12 is the contrast position of three systems.

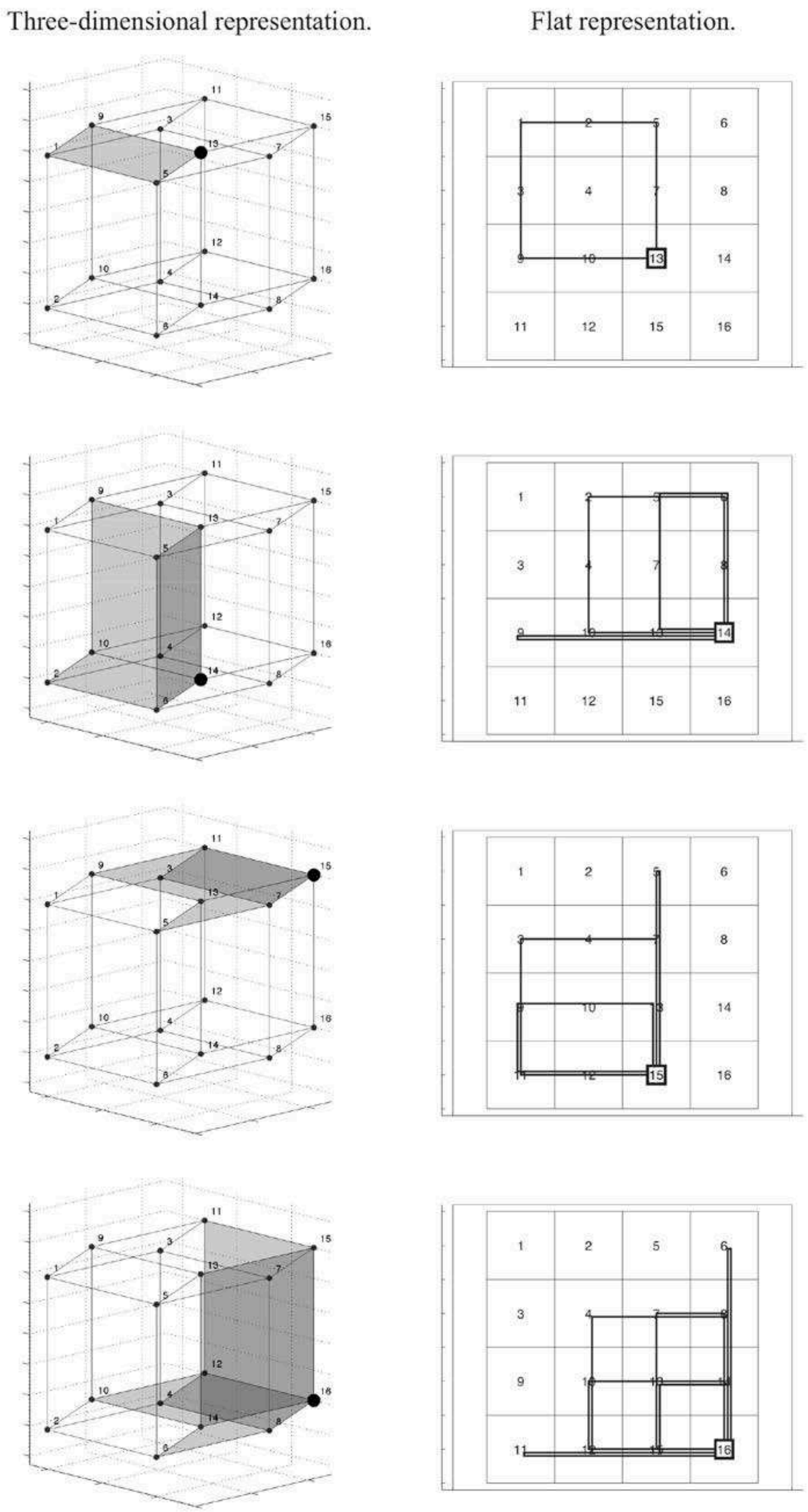

Figure 36. Hypercubic system, morphological units 13 through 16. Unit 13 is the contrast position of one system, units 14 and 15 are the contrast positions of three systems. Unit 16 is the contrast position of six systems.

Chapter IV, Section 5:
Some other configurations of the S&C model.

In **Chapter II**, we've been introducing the square form of the S&C model class. Throughout **Chapter IV**'s previous Sections, we've been describing the cubic and hypercubic forms of the S&C model. In the present Section, we recall how different forms of the S&C model class can also be considered[175], which still comply with the MDL principle as defined in **Chapter III, Section 1**.

As an example, we consider the first six bars of Antonio Vivaldi's first movement from the « Autumn » violin concerto[176], which is transcribed on **Figure 37**. We write the relation between $\boldsymbol{x}_{00}$ and $\boldsymbol{x}_{01}$ as $\boldsymbol{f}_1$, with $\boldsymbol{x}_{01} = \boldsymbol{f}_1(\boldsymbol{x}_{00})$. A high level of redundancy can be observed between $\boldsymbol{x}_{00}$ and $\boldsymbol{x}_{01}$, with $\boldsymbol{f}_1 = \boldsymbol{id}$. The relation between $\boldsymbol{x}_{00}$ and $\boldsymbol{x}_{01}$, written as *g*, is also quite simple. It includes a downward transposition of one octave of most elements, along with a change in dynamics (***f**orte* to ***p**iano*).

We quote the fundamental hypothesis written in **Chapter II, Section 2**:

> « Given a set of four consecutive units, the first three units project an implication onto the fourth unit. This implication is realized when {unit 4 is to unit 3 what unit 2 is to unit 1} and {unit 4 is to unit 2 what unit 3 is to unit 1}. Conversely, it is denied when {unit 4 is not to unit 3 what unit 2 is to unit 1} or {unit 4 is not to unit 2 what unit 3 is to unit 1}. »

We define a particular six-unit system that lies on the following hypothesis[177]:

> « Given a set of six consecutive units, and given that the relation between units 4 and 5 is the same as the relation between 1 and 2, the first five units project an implication onto the sixth unit. This implication is realized when {unit 6 is to unit 5 what unit 3 is to unit 2} and {unit 6 is to unit 3 what unit 4 is to unit 1}. Conversely it is denied when {unit 6 is not to unit 5 what unit 3 is to unit 2} or {unit 6 is not to unit 3 what unit 4 is to unit 1}. »

In regard to this hypothesis, in the case of the first six bars from Vivaldi's « Autumn », $\boldsymbol{x}_{12}$ can be described as being non-contrastive, given that one considers as residual the last three notes of the third voice being played in the same octave as in $\boldsymbol{x}_{02}$.

175 As read from Frédéric BIMBOT & al., « Complementary report to the Article “Semiotic structure labeling of music pieces: concepts, methods and annotation conventions” (Proceedings ISMIR 2012) », *op. cit.* and Frédéric BIMBOT & al., « System & Contrast: A Polymorphous Model Of The Inner Organization Of Structural Segments Within Music Pieces », *op. cit.*

176 Transcribed and adapted from Antonio VIVALDI, « Concerto in Fa maggiore per violino, archi e clavicembalo », op. 8, R.V. 293, 1723. Original edition: Eleanor SELFRIDGE-FIELD, *"The Four Seasons" and Other Violin Concertos in Full Score*, op. 8, complete, Mineola, Dover Publications, 1995. Bars 1-6.

177 In Frédéric BIMBOT & al., « System & Contrast: A Polymorphous Model Of The Inner Organization Of Structural Segments Within Music Pieces », *op. cit.*, this particular six-unit system is referred to as a « wide hexadic » system.

Use of such a model in the present case can be justified by the observation according to which expressing X_{10}, X_{11} and X_{12} in relation to X_{00}, X_{01} and X_{02} is interesting in terms of simplicity[178], since it results into a relation g that's only made from a change in dynamics and octave.

Figure 37. Study of bars 1 through 6 from Vivaldi's « Autumn » suggests a six-unit S&C model[179].

178 According to **Chapter III, Section 1** and as stated many times during the current Chapter, simplicity (compacity) of the description is a capital aspect of the current approach.

179 Other descriptions of the same excerpt are possible. In particular, at the three-bar time scale, X_{02} can be considered as contrastive in the context of the system $\{X_{00}, X_{01}, X_{02}\}$, in which case the involved relations recall Narmour's rule-mapping as seen in **Chapter II**. However, this doesn't invalidate the description as a 6-unit system. Furthermore, as seen at the beginning of the present Chapter, it is not the purpose of this work to arbitrate between descriptions belonging to different time scales.

Similar considerations can be made concerning Jedi Mind Tricks' « On the Eve of War »[180], a transcription of which is provided in **Figure 38.** This particular section is preceded by a verse featuring rapper Vinnie Paz, and followed by another verse, this time featuring rapper « Genius/GZA »[181]. The section includes, in particular, the use of different spoken vocal parts, a « scratch » part[182], and the use of a different « snare » sound.

Such differences between this particular section and the sections by which it is surrounded would make the expression of relations between its morphological units and morphological units from the other sections more complex than the expression of the relations between morphological units belonging exclusively to this section. Therefore, according to the principles expressed in **Chapter III, Section 1**, it is preferable to consider this section as a semiotic unit[183], and group the morphological units from this section into a pentadic system.

We study the system formed by these five units. Units X_1, X_2 and X_3 are the system's carrier units[184]. As in the case of a square S&C system, X_4 is conditioned by implications projected by the three carrier units. At the present stage of our research, we haven't reached conclusions in regard to the implications projected on unit $\overline{X_5}$ by units X_1 through X_4[185]. However, since we consider that morphologic unit $\overline{X_5}$ to belong to this particular semiotic unit and not to the following one, it means that we acknowledge that there are more redundancies between unit $\overline{X_5}$ and units X_1 through X_4 than between units $\overline{X_5}$ and morphological units from the following semiotic unit. For more details about this observation, see the **Appendix.**

This illustrates the observation of a pentadic S&C model. Other configurations are possible[186].

180 JEDI MIND TRICKS, « On the Eve of War, Meldrick Taylor mix », *Legacy of Blood*, Babygrande Records, 2004, 1'01-1'26. Transcription made by the author. There exist two versions for this track, be careful to actually listen to the Meldrick Taylor mix, not to « On the Eve of War, Julio Cesar Chavez ».

181 This information is provided by the records' sleeve.

182 « Scratching » refers to the act of « pushing and pulling records on the turntable to create backward sections, short stabs, loops and musical bursts », as seen in Ian PEEL, « Scratching », *Grove Music Online*, Oxford Music Online, Oxford University Press, http://www.oxfordmusiconline.com/subscriber/article/grove/music/47225 (accessed on August 6th, 2013).

183 Conditions are gathered so that we can consider this section as a semiotic unit. See **Chapter I, Section 2**, for details about semiotic units.

184 See **Chapter IV, Section 2** for the definition of a carrier unit. The system formed by $\{X_1, X_2, X_3, X_4\}$ may in the present case considered as a square S&C model. We consider it as non-contrastive, although strictly speaking it is. We consider $\overline{X_5}$ to be the contrast in this example, and X_4 the « pre-contrast ». This issue is addressed partially in Frédéric BIMBOT & al., « System & Contrast: A Polymorphous Model Of The Inner Organization Of Structural Segments Within Music Pieces », *op. cit.* We plan to study it with much more details during our planned PhD.

185 Conclusions regarding this particular aspect may be reached during our planned PhD.

186 See Frédéric BIMBOT & al., « Complementary report to the Article “Semiotic structure labeling of music pieces: concepts, methods and annotation conventions” (Proceedings ISMIR 2012) », *op. cit.* and Frédéric BIMBOT & al., « System & Contrast: A Polymorphous Model Of The Inner Organization Of Structural Segments Within Music Pieces », *op. cit.*, in which much more detail about other configurations can be found.

Figure 38. Jedi Mind Tricks' « On the Eve of War » suggests a pentadic S&C model.

Chapter IV, Section 6: Interpretation of the S&C model class.

IV.6.1. MDL and music analysis.

As in **Chapter III, Section 1**, we quote the definition of the MDL principle:

> « The Minimum Description Length (MDL) Principle is a relatively recent method for inductive inference that provides a generic solution to the model selection problem. MDL is based on the following insight: any regularity in the data can be used to compress the data, i.e. to describe it using fewer symbols than the number of symbols needed to describe the data literally. The more regularities there are, the more the data can be compressed. Equating 'learning' with 'finding regularity', we can therefore say that the more we are able to compress the data, the more we have learned about the data. » [187]

The MDL principle assumes that data compression leads to some knowledge of the data. Such knowledge may be acquired by finding the « regularities »[188] inside the data. By comparison, let's consider the definition for « music analysis » as provided by the Grove dictionary:

> « A general definition of the term as implied in common parlance might be: that part of the study of music that takes as its starting-point the music itself, rather than external factors. More formally, analysis may be said to include the interpretation of structures in music, together with their resolution into relatively simpler constituent elements, and the investigation of the relevant functions of those elements. » [189]

There is a very important bridge to be drawn between the two definitions. While MDL is concerned with « using fewer symbols than the number of symbols needed to describe the data literally », music analysis suggests « resolution [of structures] into relatively simpler constituent elements ». If we accept the hypothesis according to which the two are equivalent, we can conclude of the importance of data compression in the process of acquiring knowledge about a musical piece or extract.

Introduction of a class of models implies the hypothesis according to which, given a large corpus of data, reference to this class of model will result into significant data compression in a significant number of cases[190]. Our introduction of the S&C class of model therefore implies the hypothesis according to which, given a very large corpus of music pieces or extracts, reference to this class will be efficient in the perspective of solving a significant proportion of music pieces into relatively simpler elements. As seen in **Chapter III**, **Section 3**, such a resolution may be done at the expense of the creation of a residual part of the description, as long as the residue's size remains significantly small.

To be valid as analytical[191], given a large corpus of music pieces, the S&C model class should result into significant data compression in a significant number of cases. While experimental proof for the validity of the S&C model might conceivably be provided by the annotation of a large corpus of music pieces or extracts, such an experiment doesn't fall within the scope of this work. However, in **Chapter IV, Section 3**, we will provide several clarifications concerning the relationships between some characteristics of the S&C model class and the resolution of a significant proportion of music pieces into relatively simpler elements. But before we do so, we need to focus on a particular property of the notion of « contrast ».

187 Peter D. GRÜNWALD, Jay INJAE MYUNG and Mark A. PITT, *op. cit.*, 2005, p. 5.
188 Or, as seen in **Chapter III, Section 1**, « redundancies ».
189 Ian D. BENT and Anthony POPLE, « Analysis », *Grove Music Online*, *op. cit.*
190 As seen in **Chapter III, Section 1**, given any data, its simplest possible description, in other words its ideally compressed form, cannot be formulated. Different types of data may result into as many types of description, which leads to the introduction of models.
191 In the sense that it can considered in the purpose of music analysis, given that we accept the equivalency between « resolution into relatively simpler elements » and « [description] using fewer symbols than the number of symbols needed to describe the data literally ».

IV.6.2. An interpretation of the notion of « contrast ».

Contrasts, whatever the form they assume, will often be found near the end of the observed musical excerpt. To better understand this point of view, let's focus on the potentially contrastive units. In the context of the S&C model, implications are projected onto these units. Therefore, given implications, there arises the possibility of a denial. In the case of the square S&C model for instance, denial is possible on the fourth unit. In the case of other members of the S&C model class, the more implications are projected onto a given unit, the more possibilities of denial arise. In the case of the cubic S&C model, according to **Chapter IV, Section 3**, possibilities of denial are maximum on the eighth unit. In the case of hypercubic S&C model, according to **Chapter IV, Section 4**, possibilities of denial are maximum on the sixteenth unit. Denials of implications are therefore, by nature, found near the end of a music excerpt or semiotic segment[192].

Study of musical examples suggests that possibilities of denials are often taken advantage of[193]. For instance, in the case of the square S&C model, examination of classical « period » and « sentence » forms shows that « cadential ideas » or « new contrastive ideas » are the contrastive form of an x_{11} unit. An example of such a sentence is shown on **Figure 39**. Another example, which features this time a cubic S&C model and in a context of recent « pop » music is shown on **Figure 40**[194]. In the case of a hypercubic S&C model, the same process is used in the example shown on **Figure 32** from **Chapter IV, Section 4**, with all six implications being radically denied by the silencing of most tracks.

192 As seen in **Chapter II, Section 2,** in the case of the square S&C model, the potentially contrastive unit is the fourth one. As seen in **Chapter IV, Section 3, i**n the case of the cubic S&C model, potentially contrastive positions are 4, 6, 7 and 8, with unit 8 being the subject of three implications. As seen in **Chapter IV, Section 4, i**n the case of the hypercubic S&C model, potentially contrastive positions are 4, 6, 7, 8, 10, 11, 12, 13, 14, 15 and 16, with units 8, 12, 14 and 15 being the subject of three implications, and units 16 being the subject of six implications. Although we won't prove this particular point during the course of this work, it seems reasonable to think that the more simultaneous implications are projected onto a particular unit, the more often denials can be observed.

193 To cite only the first 40 pages of Caplin's *Classical Form*, William E. CAPLIN, *op. cit.*, 1998, example 1.1, p. 10. Example 1.3, p. 12. Example 1.4, p. 14. Example 3.2, p. 36. Example 3.3, p. 36. Example 3.4, p. 36. Example 3.11, p. 42. Many more such examples are to be found throughout the entire book.

194 In **Chapter IV, Section 3**, we've seen that unit 8 from a cubic S&C model is subject to three implications.

EXAMPLE 3.3 **(a)** Mozart, Piano Sonata in G, K. 283/189h, i, 1–10;[**(b)** rewritten version of mm. 7–10]

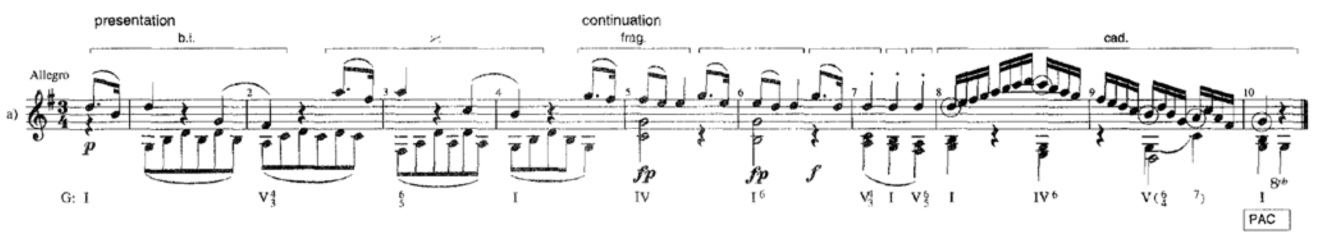

Figure 39. The cadence from this sentence spectacularly denies the implications that are projected on the corresponding morphological unit[195].

So far, we have established that contrasts, by nature, can be more often observed near the end of the observed musical excerpt, and that possibilities of denial, leading to contrastive states of elements, are often taken advantage of. Additional observation of examples of classical « period » and « sentence » forms will now provide another observation which justifies *a posteriori* the use of the term « contrast ».

As stated in Subsection IV.6.2, an important proportion of cases, period and sentence forms can be described as square S&C models, with « cadential ideas » or « new contrastive ideas » being the contrastive form of the fourth unit. Suppose we qualify a « distance » between all fourth units[196]. In the case of many period and sentence examples, the « distance » between $\overline{X_{11}}$ and all other units is greater than the « distance » between X_{00} and X_{01}, than the distance between X_{00} and X_{10}, and than the distance between X_{01} and X_{10}.

This distance between $\overline{X_{11}}$ and all other elements can serve as a measure of « contrast », in a sense that's similar to the « contrast » in pictures[197]. The first three morphological units $\{X_{00}, X_{01}, X_{10}\}$ will set a standard according to which their « distance » with X_{11} will be measured. Conversely, a high contrast brought by a very distinctive $\overline{X_{11}}$ will *a posteriori* make $\{X_{00}, X_{01}, X_{10}\}$ appear to be closer to each other, and the same $\{X_{00}, X_{01}, X_{10}\}$ will tend to appear to be more differentiated if there is no contrast, in other words if $\gamma = id$. This is represented schematically on **Figure 41**.

195 Example is Wolfgang A. MOZART, « Sonate Nr. 5 für das Pianoforte. », K. 283, 1775. Transcription from William E. CAPLIN, *op. cit.*, 1998, p. 36.

196 A « metric » in the mathematical sense.

197 For a common definition of the term « contrast » See OXFORD DICTIONARIES, « Definition of contrast in English », *Oxford dictionaries,* http://oxforddictionaries.com/definition/english/contrast (accessed on August 6th, 2013).

Figure 40: Nine Inch Nails' « The Warning »[198] provides a very clear example of all three implications projected on X_8 being spectacularly denied.

198 NINE INCH NAILS, « The Warning (Real World Remix) », *Y34RZ3R0R3M1X3D*, Interscope, 2007, 0'27-0'46. Transcription made by the author.

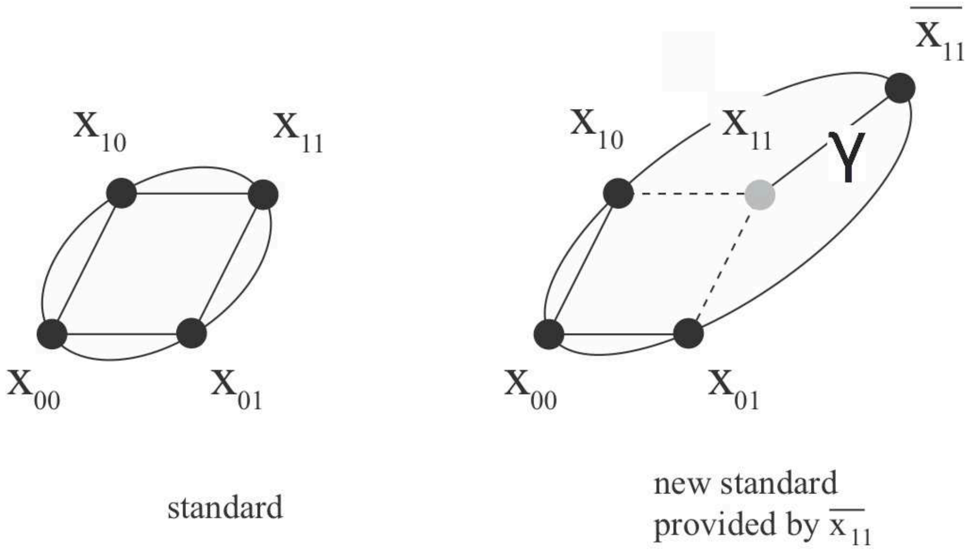

Figure 41. On the left, x_{11} is not contrastive, and $\{x_{00}, x_{01}, x_{10}, x_{11}\}$ stand at a certain « distance » from each other. On the right, $\overline{x_{11}}$ is contrastive. As a consequence, comparatively, $\{x_{00}, x_{01}, x_{10}\}$ appear to be « closer » to each other.

In both the examples shown on **Figures 39 and 40**, the fourth element of a square S&C model « dwarves » or at least « reduces » the « distances » between the first three elements. In example from **Figure 39**, would the extract be non-contrastive, bars 7-8 would be a modified repetition of bars 5-6. As it is, bars 7-8 contain a sixteenth-note pattern that's very different from bars 1-6. Knowledge of bars 7-8 provides a new standard that « reduces » the « distances » between the first 6 bars. The same phenomenon can also be observed in **Figure 11** from **Chapter II**, **Section 2,** in which the absence of the « kick, drum & hi-hat » section, along with the absence of a « bass » section, a considerable change in the « lead » part, and the introduction of new chords, greatly reduces *a posteriori*[199] the difference between x_{00}, x_{01} and x_{11}.

199 We consider that the fourth element possesses an *a posteriori* influence on the first three elements. This amounts to considering that the totality of the excerpt is unknown prior to the analysis, or, which is equivalent, that the excerpt is discovered following the course of time, as if listened to. Such an attitude is coherent with our considering of the notion of implication as fundamental. If the totality of an excerpt is known before the analysis, then the notion of implication loses much of its sense.

Such considerations shed a new light on the S&C model. Use of the S&C model implies that given a semiotic unit or any music extract that can conveniently be divided into four parts,

1. Redundancy in regard to the first part will generally be found either in the second part of in the third part.

2. Conversely, redundancy in regard to any other part will less frequently be found in the fourth part.

The same reasoning can be applied in regard to non-square S&C models. Units that are subject to implications are liable to provide *a posteriori* a new « contrast » value. « Distances » between non-potentially contrastive elements will be re-evaluated in light of the contrast brought by the potentially contrastive elements. Such a phenomenon is particularly obvious in the case of the example shown in **Figure 11** from **Chapter II**, and in the case of **Figures 39 and 40** from the present section. Conversely, the fourth morphological units in non-contrastive semiotic units doesn't increase this « contrast » value, an example of which being illustrated on **Figure 42**.

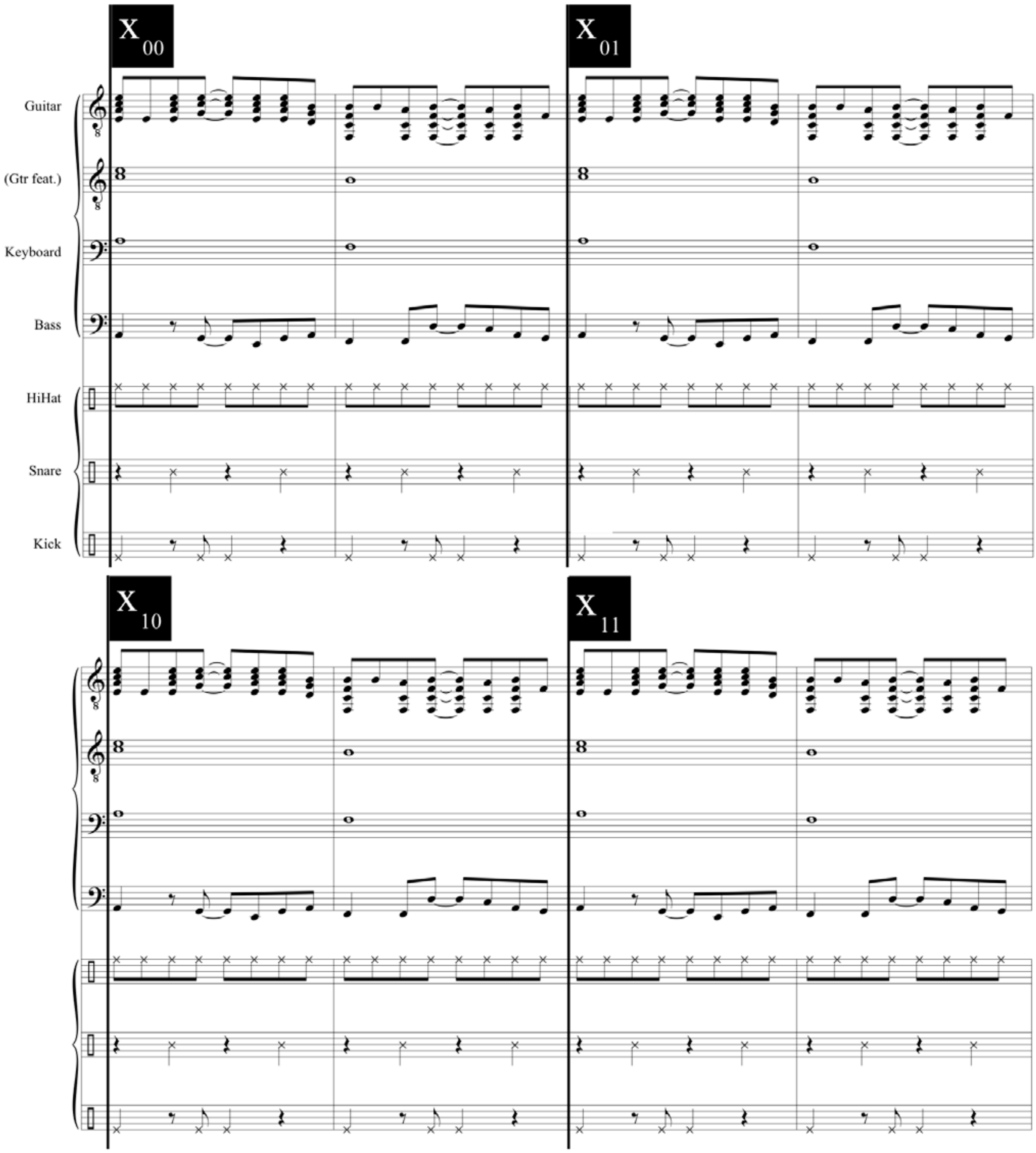

Figure 42. The fourth unit from The Cure's « Seventeen Seconds »[200] doesn't increase the « contrast » of the semiotic segment of which it belongs.

200 The Cure, « Seventeen Seconds », *Seventeen Seconds*, Fiction, 1980, 1'18-1'35. Transcription made by the author. The track noted « Gtr feat. », which stands for « Guitar featuring » or « Guitar feature » highlights the notes from the « Guitar » part that appear to be perceptively predominant.

IV.6.3. Compromise between number of models and residue size.

There are several models in the S&C class. In **Chapter III, Section 2**, we suggest that music extracts following the form of classical sentences and periods, when described using the square S&C model, result into a more compact formulation[201]. We also suggest that the same phenomenon applies to « pop » music tracks. In **Chapter IV**, **Sections 2 through 5**, we observe that changes of observation time scales suggest the existence of cubic or hypercubic unit S&C models that would also result into more compact formulations.

The existence of several such types of S&C models may be put in perspective with the issue according to which, as seen in **Chapter III, Section 1**, too many different types of descriptions may defeat the original purpose of simplicity. Conversely, a single sort of description may not be versatile enough, therefore resulting into too large a residue, with the consequence of the description defeating the original purpose of « compactness ».

This issue is represented schematically on **Figure 43**. On the left, the model is simple, or there are very few models in the class. This results into a large residue, and the description is not compact enough. On the right, the model is complicated, or there are many models in the class. This results into little or no residue, but the original purpose of simplicity is defeated. In the middle, a compromised is reached between size of the class or model and size of the residue. This is such a compromise we're after. A particular further adjustment of the S&C model class will consist in refining the number of models in the class in order to reach the best possible compromise.

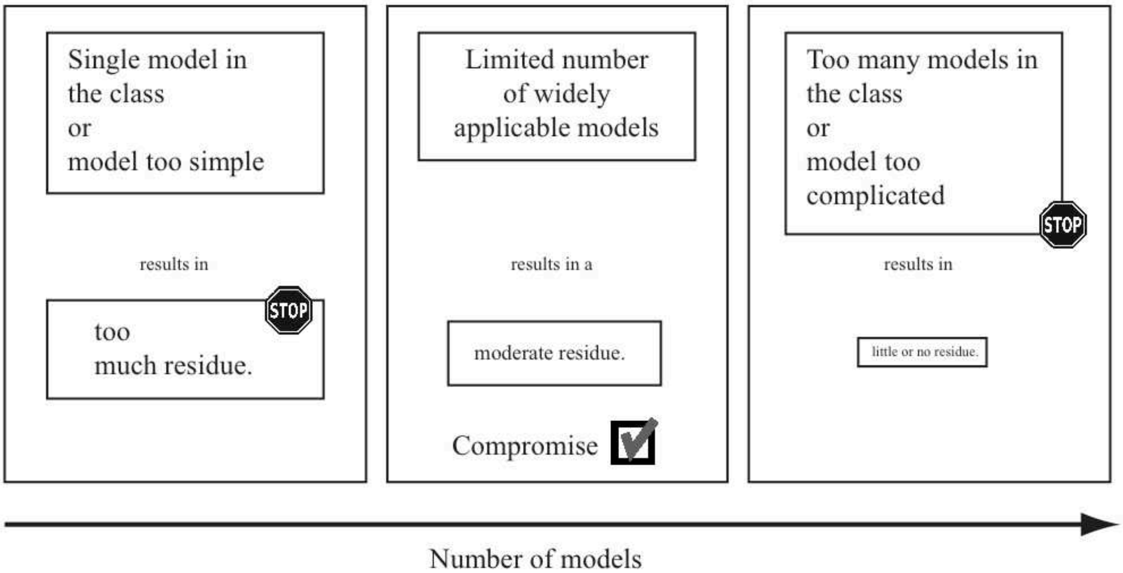

Figure 43: A compromise must be found between residue and model size[202].

201 In the case of the square S&C model $\{x_{00}, f(x_{00}), g(x_{00}), \gamma\}$, was shown to be more compact than $\{x_{00}, x_{01}, x_{10}, x_{11}\}$.

202 This is known as the « rate-distortion compromise », a notion that's common to image and audio compression, see for instance Hui CHENG, *Rate-Distortion Optimization System and Method Compression*, United States Patent No. 6,975,742 B2, 2005.

As illustrated in **Chapter III, Section 2**, underlying the S&C model class is the hypothesis according to which description of a music extract may be more compact if the model is systemic, with all morphological units derived from the first one. For instance, in the context of the square S&C model, elements 2 to 4 are derived from x_{00}, with $x_{01} = f(x_{00})$, $x_{10} = g(x_{00})$, and $x_{11} = \gamma((f \circ g)(x_{00}))$. This can be written generically as $\{x_1, F(x_1), \Gamma\}$, where x_1 is the primer, where $F(x_1)$ refers to the relations linking the other carrier units to the first one, and where Γ is the ensemble of the contrast relations[203]. Such a notation applies to other members of the S&C model class[204]. Suggesting that $\{x_1, F(x_1), \Gamma\}$ is more compact than $\{x_1 ... x_N\}$[205] implies that the consecutive morphological units are, at least to a certain extent, similar to each other[206].

This similarity of consecutive units happens to correspond with two of the three *Gestalt* principles or primitive grouping, the principles of « similarity » and « proximity »[207]. As a result, use of the S&C model will be legitimate[208] as a method of primitive grouping. Conversely, description of music excerpts that are grouped using the *Gestalt* principles of primitive grouping will necessarily benefit from the use of the S&C model.

203 In the case of the square S&C model, Γ only refers to a single contrast relation, γ. In the case of the cubic S&C model, $F(x_1)$ refers to three relations, and Γ to four contrastive relations. In the case of the hypercubic S&C model, $F(x_1)$ refers to four relations, and Γ to nine contrastive relations.

204 In the case of the cubic model class, F accounts for three relations and Γ accounts for four contrastive relations. In the case of the hypercubic model class, F accounts for four relations and Γ accounts for nine contrastive relations.

205 Where N is the number of morphological units in the system.

206 With, as a result, at least some relations between elements being simple. If all the system's morphological units have absolutely nothing to do with each other, then F and Γ will be complex, and $\{F(x_1), \Gamma\}$ will not be more compact than $\{x_2 ... x_N\}$.

207 For the notion of primitive grouping and the three *Gestalt* principles, see Bob SNYDER, *op. cit.*, 2000, p. 39-43. The third principle is which of « continuity ». It concerns similarity of consecutive relations, which strongly evokes Narmour's « rule-mapping » approach as seen in **Chapter II**, **Section 1.** Additional bibliography about the *Gestalt* theory includes the seminal article from Max WERTHEIMER, « Untersuchungen zur Lehre von der Gestalt II », *Psychologische Forschung*, IV (1923), p. 301-350. For an application of *Gestalt* theory to sound and music, refer to Albert S. BREGMAN, *Auditory Scene Analysis: The Perceptual Organization of Sound*, Cambridge, M.I.T. Press, 1990. For an application of the *Gestalt* theory to musical expectation, see Leonard B. MEYER, *Emotion and Meaning in Music*, University of Chicago Press, 1956.

208 Legitimate, in the sense that use of the model results into significant data compression.

The generic formulation for the S&C model class, $\{x_1, F(x_1), \Gamma\}$, distinguishes between relations between carrier units (x_1 with F) and the contrastive relations (Γ)[209]. As seen during the previous Subsection, Γ denotes particular natures of relations. These relations concern morphological units that are preferably situated near the end of the observed excerpt, and which express a difference between « what is » and « what could have been ». This leads to two observations according to which the expression of Γ is more interesting than an expression of F-like relations leading to the same elements:

- The expression of the concerned morphological units in terms of difference between « what is » and « what could have been » brings additional knowledge[210] about the observed excerpt, in the sense that not only it describes the excerpt as it is, it also describes the implications involved[211].
- This providing of both contrastive and non-contrastive states of particular morphological units ensures better data compression in cases in which both states are actually provided, such as the example shown in **Figure 38** from **Chapter V, Section 5**.

It also leads to the formulation of an underlying hypothesis, according to which there is a privileged relation between contrastive and non-contrastive states of morphological units, in the sense that both would either belong to the same class **(Figure 42**), or on the contrary be conjugates **(Figure 40**)[212]. This is a point of view that will be consolidated during our planned PhD.

To summarize, two of the hypotheses underlying the S&C model class can be formulated as follows:

1. Given a large number of music pieces or excerpts, describing the elements in relation to the first one instead of expressing them literally will generally result into a more compact description[213]. This view is compatible with two of the three main principles at work in primitive grouping in the *Gestalt* sense.
2. Given a large number of music pieces or excerpts, describing the potentially contrastive units in relation to their non-contrastive state will generally result into a more efficient description. This illustrates an underlying hypothesis according to which the relations between the contrastive and non-contrastive forms of units are to be privileged.

This concludes the present Chapter. We will now focus on practical case studies.

209 As seen in **Chapter II, Section 2**, in the case of the square S&C model, we have $\Gamma = \gamma$, where γ is defined by $x_{11} = \gamma((f \circ g)(x_{00}))$.

210 « Knowledge » in this case remains compatible with its interpretation in the light of the MDL principle, as seen during the first Subsection of the present Section.

211 In the light of the temporary dismissal of the difference between perceptual and logical contexts mentioned in **Chapter II, Section 1**, it also brings information about expectations in a more general sense.

212 In the example, implied active tracks consist in all but the « vocal » one, whereas the actual contrastive unit is built from the « vocal » track only. In terms of active tracks, contrastive and non-contrastive states are conjugate.

213 And therefore to a better understanding of the musical content.

CHAPTER V: CASE STUDIES.

In this Chapter, we describe several music examples using the S&C model class. Every one of these examples belonging to recent popular music, we start the Chapter by providing context for such a choice.

Chapter V, Section 1:
Recent popular music and « inversion of pertinences ».

During the course of this work, we've been dealing with a number of music examples belonging to the Viennese classical period[214], as well as a number of music examples belonging to recent trends of popular music[215]. This choice is made on ground of regularity of the music to be described. At the current point of this research, description of less « regular » music such as music from the Romantic period poses a number of problems that we don't intend to solve with the present work, but rather with our planned PhD.

Comparison of the respective amount of studies concerning music from the Viennese classical period and recent popular music shows a definite general tendency towards analyses of the former[216]. This suggests that additional analyses, or at least descriptions, of recent popular music might be a more useful contribution than descriptions of music from the Viennese classical period[217]. However, before we provide such descriptions, we feel the need to provide a « stylistic » context in regard to popular music.

214 Amongst others and in no particular order, Wolfgang A. Mozart in **Chapter I, Section 3,** in **Chapter II, Section 2**, in **Chapter III, Section 2**, as well as in **Chapter IV, Section 2**, Franz J. Haydn in **Chapter III, Section 2**, Ludwig Van Beethoven in **Chapter I, Section 3.**

215 Amongst others and in no particular order, the French metal band Gojira in **Chapter III**, **Section 3**, the American rap band Jedi Mind Tricks in **Chapter IV**, **Section 5**, the American singer Britney Spears in **Chapter II, Section 2**, the American band Nine Inch Nails in **Chapter IV, Section 4**. In Philip TAGG, « Analyzing Popular Music: Theory, Method and Practice », Popular Music, II (1982), p. 40, Philip Tagg provides a difference between so-called « art music », « folk music » and « popular music ». According to this classification, « popular music » is a music based on recorded sound, primarily made by professionals, and destined for mass distribution.

216 See, amongst many others, William E. CAPLIN, *op. cit.*, 1998. In this single reference, one can find more than a hundred analyses.

217 This doesn't compromise the usefulness of the S&C model class for the description of music from the Viennese classical era.

François Delalande[218] compares the importance of what he calls « sound » in music as written by Girolamo Frescobaldi (1583-1643)[219] to its importance in music as played by Ornette Coleman (born 1930)[220]. Delalande's argument can be summed up in that in Frescobaldi's case, « sound » possesses no pertinence[221]. This is related to the fact that the execution of an instrumental piece at the beginning of the XVII[th] century had to rely on the instruments that were available at the moment of the performance, therefore leading to pieces considered as « musical counterpoint which could be played on harpsichord, organ or even by an instrumental ensemble »[222]. The musical discourse is carried by information found on the score, a score in the like of the manuscript shown on **Figure 44**.

Figure 44. A manuscript by Girolamo Frescobaldi. The score only keeps tracks of information about pitch and time.

One can read sequences of notes, possibly superimposed, notes whose sole written properties are pitch and duration. Throughout the course of history, scores will grow to keep track of other layers of information. However, as « the first important European composer to concentrate on instrumental music »[223], Frescobaldi only transcribes pitch and time information. We will use this particular state of the art as a landmark, referring to such scores as « Frescobaldian scores ».

218 François DELALANDE, *Le Son des Musiques*, Buchet/Castel, 2001, p. 21-23.
219 Alexander SILBIGER, « Frescobaldi, Girolamo Alessandro », *Grove Music Online*, Oxford Music Online, Oxford University Press, http://www.oxfordmusiconline.com/subscriber/article/grove/music/52537 (accessed on July 24th, 2013).
220 Gunther SCHULLER, « Coleman, Ornette », *Grove Music Online*, Oxford Music Online, Oxford University Press, http://www.oxfordmusiconline.com/subscriber/article/grove/music/06079 (accessed on August 6th, 2013).
221 According to Delalande, what is « pertinent » is what carries the meaning of the message. For instance, considering the word « canone » in Italian, the place of the tonic accent is pertinent. A tonic accent on the first syllable refers to the musical form, a tonic accent on the second syllable refers to the weapon. Conversely, changing the place of a tonic accent in French generally won't change the meaning of the word.
222 Alexander SILBIGER, *op. cit.*, Grove Music Online.
223 Alexander SILBIGER, *op. cit.*, Grove Music Online.

Conversely, in the case of Ornette Coleman's music, the picture is entirely different. François Delalande quotes the following recommendation from Coleman: « Think about sound... always think about sound more than you think about notes... notes are not important... the notes, you can change them »[224]. According to such a point of view, the musical discourse appears to be carried by what's not written on the « Frescobaldian score », i.e. by the layers of information that are referred to by both Delalande and Coleman as « sound »[225]. In regards to Coleman's music, such layers of information may include instrumental timbre, expression, *rubato*, agogic[226], dynamics, articulation...

This opposition between two such visions of music is so obvious that François Delalande concludes to what he refers to as an historical « inversion of pertinences » between Frescobaldi and Coleman. What constitutes music according to the former has no importance to the latter. To use notions borrowed from structural linguistics, what's « denotative » in the case of Frescobaldi (notes and durations) becomes « connotative » in the case of Coleman[227].

This phenomenon, according to which « musical parameters » from the « Frescobaldian score », such as pitch and duration, would become connotative, while many musical parameters that are foreign to such a score, such as « timbre »[228], articulation and dynamics, would become denotative, can be supported by the observation of a number of pieces of music over the course of western music history. We illustrate such an evolution by a timeline that can be found below. In regard to the cited examples, a gradual rise in the importance of « sound » or « timbre »-related musical parameters can be witnessed, sometimes at the expense of pitch and duration.

We consider the following examples:

- Girolamo Frescobaldi, ca. 1600. Specific instruments are routinely not indicated on the score.
- Johann S. Bach, ca. 1725. Specific instruments may be indicated on the score[229].
- Wolfgang A. Mozart, ca. 1775. Instruments are always indicated on the score, to the point that orchestration may sometimes be deemed as determinant of musical structure[230].
- Jean-Georges Kastner, 1837 and Hector Berlioz, 1843. First treatises of orchestration[231].
- Claude Debussy, ca. 1900. Devotes an extreme attention to timbre[232].

224 François DELALANDE, *op. cit.*, 2001, p. 21-23.

225 It is not our prerogative to judge whether the term « sound » is suited to what Coleman and Delalande actually refer to. In the present case, our ambition is merely to report their point of view.

226 For a definition of the term, see Matthias THIEMEL, « Agogic », *Grove Music Online*, Oxford Music Online, Oxford University Press, http://www.oxfordmusiconline.com/subscriber/ article/grove/music/20404 (accessed on August 6th, 2013).

227 The terms are borrowed from Umberto ECO, *A Theory of Semiotics*, Indiana University Press, 1979, p. 55, as well as from Raymond MONELLE, *Linguistics and Semiotics in Music*, Harwood Academic Publishers, 1992, p. 136. For additional information about the notions of connotation and denotation, see respectively Robert SCTRICK, « Dénotation », *Encyclopædia Universalis en ligne*, http://www.universalis-edu.com/encyclopedie/denotation (accessed on June 14th, 2013) and Philippe DUBOIS, « Connotation », *Encyclopædia Universalis en ligne*, http://www.universalis-edu.com/encyclopedie/connotation (accessed on June 14th, 2013). Much more could be said about connotation and denotation in music. This is one aspect we plan to detail in the context of our planned PhD.

228 We choose put the term « timbre » in between quotes. A reading of Pierre SCHAEFFER, *Traité des objets musicaux*, Seuil, 1966, as well as its exegesis Michel CHION, *Guide des objets sonores*, Buchet/Castel, 1983, will show that the notion of « timbre » is complex and far from being properly defined.

229 Many examples can be provided, amongst which Johann S. Bach specific indications of whether he'd write for harpsichord or organ. This is confirmed by Christoph WOLFF & al., « Bach, §III: (7) Johann Sebastian Bach », *Grove Music Online*, Oxford Music Online, Oxford University Press, http://www.oxfordmusiconline.com/subscriber/ article/grove/music/40023pg10 (accessed on August 6th, 2013), in which one can read that « right from the beginning, consistently and in defiance of inherited 17th-century tradition, [Bach] abandoned the conventional community of repertory between organ and harpsichord, choosing to write specifically for the one or the other. ».

230 Jonathan P. J. STOCK: « Orchestration As Structural Determinant: Mozart's Deployment Of Woodwind Timbre In The Slow Movement Of The C Minor Piano Concerto K. 49 », *Music and Letters*, DXXVIII/2, p. 210-219, 1997.

231 Hector BERLIOZ: *Grand Traité d'Orchestration et d'Instrumentation Modernes*, Henry Lemoine, 1843. Kenneth KREITNER & al., « Instrumentation and Orchestration », Grove Music Online, Oxford Music Online, Oxford University Press, http://www.oxfordmusiconline.com/subscriber/ article/grove/music/20404 (accessed on July 1st, 2013). Patricia J. WOODWARD: *Jean-Georges Kastner's Traité Général d'Instrumentation: A Translation And Commentary*, submitted in partial fulfillment of the requirements for the Master of Arts degree in Music at the University of North Texas, May 2003.

232 As testified in François LESURE and Roy HOWAT, « Debussy, (Achille-)Claude », *Grove Music Online*, Oxford Music Online, Oxford University Press, http://www.oxfordmusiconline.com/subscriber/article/grove/music/07353 (accessed on August 6th, 2013), « [Debussy's] interest in resonances is reflected in his own salon piano, a Blüthner boudoir grand with the Aliquot system of a

- Karlheinz Stockhausen, 1968. Writes « Stimmung », a 70-minute piece based on one single chord[233].

- Lil' Wayne, 2009. Performs « A Milli », nominated best rap performance at the 51st *Grammy Awards*[234], which practically doesn't contain pitch that could be written down on a score.

Many more examples could be cited. Such an « inversion of pertinences » is not an isolated notion. Several authors have tried to characterize similar issues, even though their vocabulary may not be similar. Amongst them, William Moylan and Serge Lacasse question the nature of the « primary level » or « primary carrier » of the musical message in case of « popular music »[235]. Similarly, Richard Middleton questions the existence of the « primary level of signification » in popular music[236]. Such considerations are clearly related to the notion of « determinant of form » as defined by Caplin[237], as well as the opposition Narmour defines between « rule mapping » and « stylistic mapping »[238].

supplementary string to each note in the upper register which resonates sympathetically without being struck ». According to the same article, « he went so far as to imagine a complete revolution in the seating arrangement of the orchestra in order to realize his dream of an ideal sound, with the strings forming a circle round the other instruments, the woodwinds dispersed, the bassoons among the cellos, and the clarinets and oboes among the violins 'so that their intervention becomes something other than the dropping of a parcel' ». Finally, for Debussy, « timbre was not merely a coat to be added to the musical texture, but became an essential element of his musical language ».

233 Karlheinz STOCKHAUSEN: *Conversations with the composer*, edited by J. Cott, Robson, 1974, p. 38.

234 GRAMMY.COM, « Past Winners Search », *Grammy.com*, http://www.grammy.com/nominees/search? artist=wayne &field_nominee_work_value=milli&year=All&genre=28 (accessed on August 6th, 2013).

235 William MOYLAN, *Understanding and Crafting the Mix, the Art of Recording,* Focal Press, 2007, p. 67-70. Serge LACASSE, *op. cit.*, 2000, p. 170-171.

236 Richard MIDDLETON, *Studying Popular Music*, Milton Keynes, 1990, p. 220-232. Richard MIDDLETON, « Popular Music Analysis and Musicology: bridging the gap », *Popular Music*, XII, 1993, p. 177-190.

237 William E. CAPLIN, *op. cit.*, 1998, p. 4. For Caplin, the determinant of form is the ensemble of musical layers that underlie the formal relations.

238 See Table 1 in Eugene NARMOUR, *op. cit.*, 2000, p. 340.

In this regard, we will therefore suggest a convergence between several couples of antagonist notions:

- Pertinence / non-pertinence[239].
- Denotation / connotation[240].
- Carrier / modulation[241].
- Primary level of signification / secondary level of signification[242].
- Determinant of form / non-determinant of form[243].
- Rule-mapping / stylistic mapping[244].

While it does not belong to the scope of the present work to solve the question whether such couples are equivalent, this is a particular problem that we ought and plan to consider in the course of our PhD. For the time being, these are notions that will turn out to be useful in regard to the issues we'll be dealing with during the following Section.

239 François DELALANDE, *op. cit.*, 2001, p. 21-23.
240 Raymond MONELLE, *op. cit.*, 1992. Umberto ECO, *op. cit.*, 1979, Robert SCTRICK, *op. cit.*, *Encyclopædia Universalis en ligne*, Philippe DUBOIS, *op. cit.*, *Encyclopædia Universalis en ligne.*
241 See **Chapter IV, Section 1.**
242 William MOYLAN, *op. cit.*, 2007. Serge LACASSE, *op. cit.,* 2000. Richard MIDDLETON, *op. cit.*, 1990, 1993.
243 William E. CAPLIN, *op. cit.*, 1998, p. 4.
244 Eugene NARMOUR, *op. cit.*, 2000, p. 340.

Chapter V, Section 2:
About « studio-based popular music. »

We need to provide a characterization for the class of modern « popular music » from which, as seen at the beginning of this Chapter, we draw a number of examples. We will define as « studio-based popular music » a trend of popular music in the context of which the recording medium is used for its unique creative potentials[245], with the studio being used as a musical instrument[246]. This trend can be considered as starting since the early or mid 1960's[247], most notably with the beginning of the Beatles' recording career[248]. While this may not be the type of popular music we will exclusively be dealing with, such a definition provides a landmark in regard to which we'll be able to reason.

The gradual « inversion of pertinences » over time mentioned in **Chapter V, Section 1**, possesses a particular importance in regard to « studio-based popular music ». Pointing out that some music scholars dismiss most of recent popular music on grounds that its harmony would reputedly be based on simplistic chord sequences, Philip Tagg objects to such a dismissal, observing that the same music scholars would never « dismiss late Beethoven quartets on grounds on mono-metricity, mono-timbrality and mono-spatiality »[249]. In other words, according to Philip Tagg, in order to understand « popular music », one should consider rhythm, timbre and space as pertinent elements of the musical discourse. Put differently, one should be aware of the « inversion of pertinences » mentioned by François Delalande.

As seen in **Chapter V, Section 1**, pertinences and « primary levels of signification » of the musical discourse in studio-based popular music are part of a complex problem that we won't be able to solve in the context of the present work. However, during the previous Chapters, we believe we've been defining tools that relate to this problem and may consist in a first approach towards the resolution of the issue. First of all, in **Chapter III, Sections 1 and 2**, we've been showing that observation of redundancies in the musical discourse may result into the definition of relations between elements[250] that may provide an acceptable description[251] of the considered music piece or extract. Specification of the « musical parameters » on which these relations are based may consist in a first hint towards the specification of the « primary levels of information » or « pertinent layers » of the musical discourse. Furthermore, as developed in **Chapter IV, Section 1**, the contrast can be considered as a logical modulation of a carrier generated by the carrier units. Similarly, specification of the « musical parameters » on which this logical modulation is expressed may also provide a hint towards the specification of « primary levels of information » mentioned in **Chapter V, Section 1**[252].

Chapter V, Section 3:
Particular musical examples.

In this Section, we describe music pieces using the S&C model class. These pieces primarily belong to the studio-based popular music genre as defined in **Chapter V, Section 2.** As explained in **Chapter V, Section 1**, such a focus on this music genre is motivated by the sparsity of analyses of such music found in the literature[253]. We also

245 William MOYLAN, *op. cit.*, p. 270.

246 Virgil MOOREFIELD, *The Producer as Composer: Shaping the Sounds of Popular Music*, M.I.T. Press, 2005, p. 43-78.

247 William MOYLAN, *op. cit.,* 2007, p. 270. For the Beatles, see Walter EVERETT, « Beatles, the », *Grove Music Online*, Oxford Music Online, Oxford University Press, http://www.oxfordmusiconline.com/subscriber/article/grove/music/ 02422 (accessed on August 7th, 2013).

248 Greg MILNER, *Perfecting Sound Forever, an Aural History of Recorded Music*, Faber&Faber, 2010, p. 157.

249 Philip TAGG, *Everyday Tonality*, The Mass Media Music Scholar's Press, 2009, p. 160.

250 For instance, the relations *f* and *g* from the square S&C model.

251 Acceptable in the MDL acceptation of the word, as seen in **Chapter III, Section 1**.

252 We have to signal the fact that Raymond Monelle hints towards a similar point of view in Raymond MONELLE, *op. cit.*, 1992, p. 64, although his interpretation of the notions of « contrast », « carrier » and « modulation » in regards to ours would require a detailed discussion including, amongst other things, issues related to the field of semiotics. Although we may consider such a discussion in the context of our planned PhD, we won't be including it in the context of the present work.

253 In Christophe PIRENNE, *Une histoire musicale du Rock*, Fayard, 2011, the author mentions the fact that many books or articles about « popular music » don't consider the music as a starting point. He justifies his choice of the term « musical » in the book's title (in english, *A musical history of Rock*) as an emphasis that he takes music as a starting point. Nevertheless, Christophe Pirenne's

show interest towards finding the « determinant of form » in studio-based popular music[254]. We suggest that the characterization of the « musical parameters » taking part in F and Γ may constitute a potentially useful hint towards the finding of such a determinant of form.

V.3.1. Psy, « Gangnam Style ».

In this Subsection, we show how different members of the S&C model class can be used to describe a particular extract from a well-known « pop » song that takes considerable advantage of the notion of implication. In particular, we show how it is possible to better « learn » about the main « gimmick »[255] when all gimmick occurrences are considered as belonging to a single non-contrastive system. An important particularity of such a system is that it's not contrastive, whereas each of its element is contrastive when taken as the fourth element of other systems.

The song we describe is « Gangnam Style » by Korean singer « Psy », a transcription of which is given on **Figure 45**[256]. This is a section that can be considered as a semiotic unit according to **Chapter I, Section 2**. We will mainly describe this section using the square form of the S&C model, although we may also consider instances of the cubic or hypercubic S&C models.[257].

book is primarily about the history of « rock ». Analyses of « popular music » pieces without resort to any sort of cultural context are, in our knowledge, even more rare. A few of them can be found in Virgil MOOREFIELD, *op. cit.*, 2005. Some can also be found in William MOYLAN, *op. cit.*, 2007. However, in this particular case, their focus lie primarily on the « sound image » aspect of the music.

254 For considerations on the « determinant of form », see William E. CAPLIN, *op. cit.*, 1998, p.4.

255 We call a « gimmick » the part of the chorus that repeats the song's title.

256 PSY, « Gangnam Style », *Now vol. 44*, EMI, 2012, 1'12-1'25. In July 2013, this is the track with the highest YouTube visit number ever, as seen on YOUTUBE.COM, « Most viewed videos », http://www.youtube.com/charts/ videos_views?t=a&gl=US (accessed on July 10th, 2013).

257 However, as explained at the beginning of **Chapter IV**, during the course of the present work, we won't be providing definitive arguments for the selection between square, cubic, and hypercubic models.

We study the « Key » (keyboard) part, of which we consider descriptions that take advantage of redundancies in order to user fewer symbols than the number of symbols needed to describe the data literally[258]. These descriptions are shown on **Figure 46**.

1. Description 1 includes bar 1 only. A « period »-like form can be observed, with a high degree of redundancy between X_{00} and X_{10}. The system is presented in a contrastive state.

2. Description 2 considers bars 1 and 2, with each morphological unit lasting two beats. The two units X_{00} and X_{10} are identical, and the system is presented in a contrastive state.

3. Description 3 includes bars 1 through 8, with each morphological unit lasting one bar. Redundancies between morphological units X_{00}^{A} and X_{10}^{A} on the one hand, and between X_{01}^{A} and X_{11}^{A} on the other hand justify the use of a description of bars 1 through 4 using a non-contrastive form of a square S&C model. Also, redundancies between morphological units X_{00}^{B} and X_{10}^{B} justify the use of a description of bars 5 through 8 using a contrastive form of a square S&C model.

4. Description 4 considers bar 1 through 8 as a single cubic model. No morphological units are contrastive except for $\overline{X_{8}}$[259]. All the three implications that condition X_{8} converge, and all of them are denied. The choice between one the three S&C systems that underlies each implication doesn't appear to be obvious[260].

There are two remarks to be made in regard to the description of this keyboard part. First, we find the number of S&C models that can be used in order to describe the part impressively high, even though our description does not aim at being exhaustive[261]. The second remark comes a consequence of the first. The keyboard part in Psy's « Gangnam Style » is apparently written so as to generate a constant stream of implications, which can either be realized or denied.

258 This is still in accordance with **Chapter 3, Sections 1 and 2**. Notice that the list of S&C models we give here is by no mean exhaustive. Description of the other tracks, most notably the « Kick », « Snare », and « HH&percs » tracks, can be efficiently made using a hypercubic S&C model. Instantiation of such an assertion is left to the reader's appreciation.

259 Which provides a considerable raise in « contrast » in the sense defined in **Chapter IV, Section 6** and illustrated on **Figure 42** from the same Section.

260 See **Chapter IV, Section 3** for more details on the issue of conflicting implications.

261 The subjectivity of such a remark doesn't necessarily make it wrong.

Figure 45. Transcription of a semiotic unit from Psy's « Gangnam Style »[262].

We now focus on the « Lead » part. If we describe bars 1 and 2 as a square S&C model, then the voicing of the « Gangnam Style » gimmick comes as an important contrast, or, put differently, as a considerable denial of implications projected on x_{11}. Alternatively, we can describe the « Lead » part using different instances of the S&C model. Bars 1 through 4 on the one hand, and bars 5 through 8 on the other hand, can be considered as a square S&C model. Bars 1 through 8 can be considered as a cubic S&C model. The entire « Lead » part can be described as a hypercubic S&C model, each morphological unit lasting two beats.

262 The « Lead » track corresponds to the lead vocal part. The « Key » track corresponds to the main keyboard part. The « HH&percs » track corresponds to the hi-hat part, along with similar-sounding percussions. The « Crash », « Snare » and « Kick » tracks correspond to the same instruments as described in **Chapter IV, Section 5.**

In all cases, the systems are contrastive, except on two occasions. If bars 1 through 8 are considered as a cubic S&C model, then the system grouping all four instances of the « Gangnam Style » gimmick (bars 2, 4, 6 and 8) is not contrastive. Similarly, if we describe the « Lead » part as a hypercubic S&C model, then the four instances of the « Gangnam Style » gimmick are identical and therefore not contrastive.

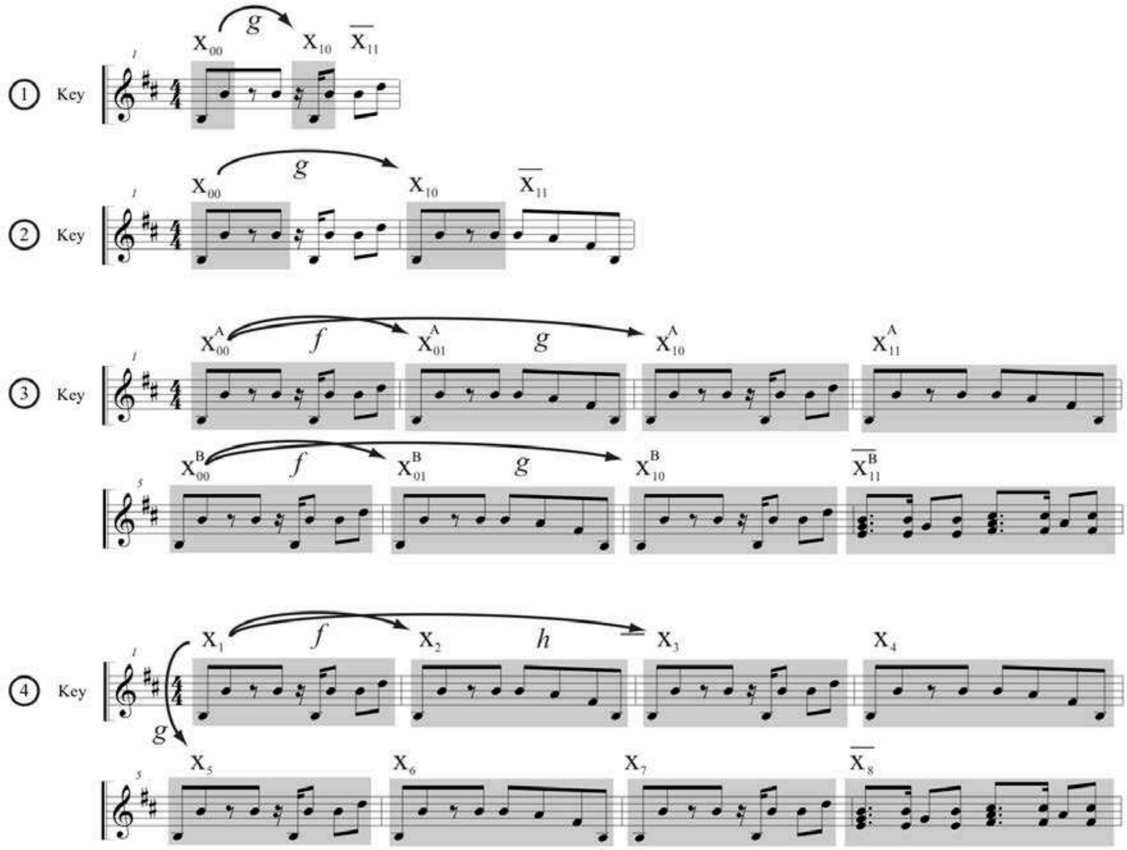

Figure 46. Different descriptions of the « Key » (keyboard) part in Psy's « Gangnam Style ».

We can conclude that such a handling of the voicing of the song's title is notable, in the sense that the « Gangnam Style » gimmick can be more efficiently compressed when considered independently from the other elements[263]. Given the song's considerable popularity, this may hint towards the fact that part of the recipe for a « hit » may lie in the presence of a very simple system containing the gimmick. Other systems may be made from more complicated relations, or they may be contrastive, but the system featuring the gimmick may have to be as simple as possible.

263 And therefore, as seen in **Chapter III, Section 1,** better « learnt » about.

V.3.2. M.I.A., « Meds and Feds ».

In this Subsection, we show how a semiotic unit from a song by a popular singer[264] uses « musical dimensions » or « parameters » that may relate to the « dimensions » used in a music piece by contemporary music composer Pierre Boulez[265]. The song we describe is « Meds and Feds » by British singer M.I.A., a transcription of which is shown on **Figure 47**[266]. This is a section that can be considered as a semiotic unit according to **Chapter I, Section 2**.

We choose to describe this semiotic unit using a cubic S&C model. This choice is motivated by the numerous redundancies observed at this particular time scale[267]. We start the description of the piece by trying to separate the « systemic » from the « residual »[268]. Listening to the song's other semiotic segments, we observe that the « Kick » pattern « quarter note, two eighth notes, quarter note, quarter note » occurs only during the present semiotic segment. Such an observation, added to the fact that the difference between « quarter note, two eighth notes, quarter note, quarter note » and « four quarter notes » is small, leads us to characterize the second eighth note in bars 3 and 4 as residual.

We now observe the bottom part of the « Vocals » track during bar 1, and compare it to the bottom parts of bars 2 through 4, which are exactly the same. We conclude that we're in a situation that's similar to the one observed in **Figure 21** from **Chapter III, Section 3.** Such a situation can be summed up as follows: considering the first four morphological units as a square S&C model, with $x_2 = f(x_1)$, $x_3 = g(x_1)$ and $x_4 = k(x_1)$, then the expression of the contrastive relation $\gamma = k \circ (f \circ g)^{-1}$ would be much longer and much less simple than the residual difference between x_1 and x_2, or x_3, or x_4.

Without the residue, the semiotic unit from **Figure 47** becomes as shown on **Figure 48**[269]. The « Snare » and « Kick » parts are non-contrastive. As far as the « Guitar » part is concerned, all the implications towards x_8 converge[270], and are denied, therefore making $\overline{x_8}$ contrastive. We now focus on the « Vocals » part, which we can divide into two parts. The upper part consists in a « s »-like sound. Similarly to what is observed with the « Guitar » part, units x_1 through x_7 project converging implications on $\overline{x_8}$, which denies them all. Let's observe the lower part of the vocal track, units 5 to 8:

- x_5 is a carrier unit, $x_5 = g(x_1)$ and $g = id$.

- $\overline{x_6}$ is the fourth element of the system $\{x_1, x_2, x_5, x_6\}$. The implications projected on $\overline{x_6}$ are denied. The contrast relation consists in part into the transformation of eighth notes 3, 4, and 8 into an ascending melodic movement. It also consists into the transformation of previously non-intelligible « syllables » into accented, intelligible syllables. We find this particular point to be noteworthy, on the ground that it turns accentuation and syllable intelligibility into a musical parameter[271].

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264 Andy KELLMAN, « M.I.A. », Artist Biography by Andy Kellman », *AllMusic.com*, http://www.allmusic.com/artist/mia-mn0000388773/biography (accessed on August 8th, 2013).

265 Georges W. HOPKINS and Paul GRIFFITHS, « Boulez, Pierre », *Grove Music Online*, Oxford Music Online, Oxford University Press, http://www.oxfordmusiconline.com/subscriber/article/grove/music/03708 (accessed on August 8th, 2013).

266 M.I.A., « Meds and Feds », *MAYA*, Interscope, 2010, 2'39-2'52. Transcription made by the author. We choose this song as an example on the ground that it provides a specific handling of particular musical « parameters » or « dimensions » that we find worthy of interest.

267 And according to **Chapter III, Section 2**, the more redundancies, the more data compression is possible, and the more we « learn » about the data, in this case the music.

268 See **Chapter III, Section 3** for the distinction between « systemic » and « residual ».

269 Removal of the residual can result in the actual addition of elements. In bar 1, the residual mainly consists in the absence of notes. Therefore, removal of the residual results in addition of notes.

270 As seen in **Chapter IV, Section 3,** in the context of a cubic S&C model, x_8 is subject to three potentially conflicting implications.

271 And, according to **Chapter V, Section 1**, to a potentially pertinent / denotative / carrier musical parameter that could be considered as a determinant of form / primary level of signification / subject to rule-mapping.

- $\overline{X_7}$ is the fourth element of system $\{X_1, X_3, X_5, X_7\}$. The implications projected on $\overline{X_7}$ are denied. The contrast relation consists in part into the transformation of eighth notes 3, 4 and 8. More notably and similarly to what we've been observing in the case of $\overline{X_6}$, it also consists into the transformation of previously non-intelligible syllables into accented, intelligible ones.

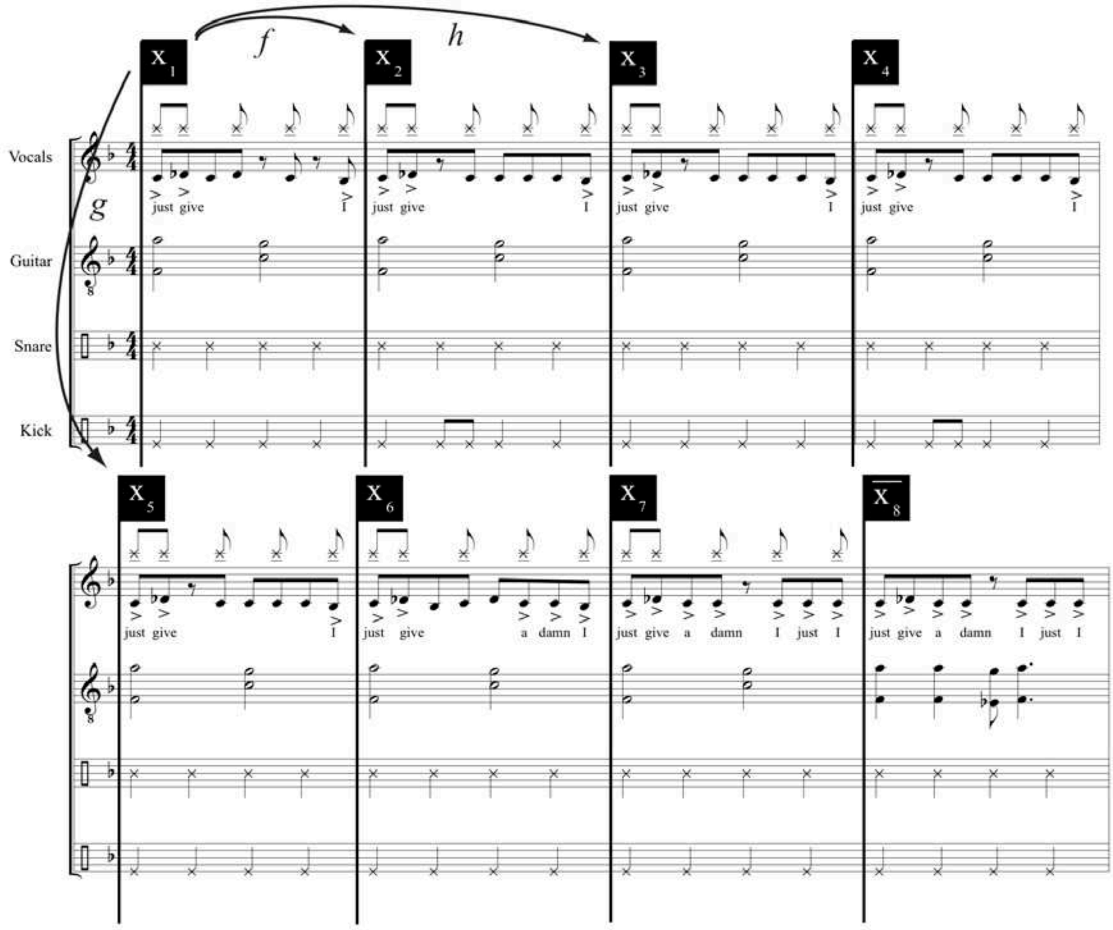

Figure 47. Transcription of a section from M.I.A's « Meds and Feds »[272]

- As seen in **Chapter IV, Section 3**, X_8 is the fourth unit of systems $\{X_2, X_4, X_6, X_8\}$, $\{X_3, X_4, X_7, X_8\}$ and $\{X_5, X_6, X_7, X_8\}$. All implications projected onto $\overline{X_8}$ are denied. As far as the lower part of the vocal track is concerned, $X_7 = X_8$. X_6 being more similar to X_7 and X_8 than X_3, it is preferable to consider $\overline{X_8}$ as the fourth unit of system $\{X_5, X_6, X_7, X_8\}$.

Let's sum up the musical parameters on which the vocal part is built. The first five units are identical. The contrast relations leading to $\overline{X_6}$ and $\overline{X_7}$ are based on a modification of the melody, along with the transformation of non-intelligible syllables into accented intelligible ones. Finally, $\overline{X_8}$ is identical to $\overline{X_7}$.

272 On the transcription, some of the notes from the vocal part are not associated to lyrics. This corresponds to syllables that are not understandable. Also, the top notes from the vocal part correspond to occurrences of « s » sounds that are apparently of vocal origin, and which are superimposed and partly synchronized to the « standard » vocal part.

As illustrated on **Figure 49**, such a systemic use of accents is somewhat reminiscent of Pierre Boulez's *Messagesquisse*[273]. In relation to Philip Tagg's remark as mentioned in **Chapter V, Section 2,** it suggests that as far as studio-based popular music is concerned, « pertinent » elements of the musical language may have to be sought after in musical « dimensions » that are closer to « contemporary » music than they are to the traditional western harmonic language[274].

V.3.3. Gojira, « Planned Obsolescence ».

In this Subsection, we show how an excerpt from a song that, at first hearing, may appear to be confusing, noisy and difficult to decipher, can be easily described using a square S&C model. The song we consider is Gojira's « Planned Obsolescence »[275], for which a transcription is given in **Figure 50.** Simultaneously, we show how the residual part of a description may not only consist into the addition or subtraction of elements, but also in a transformation of the original content.

We refer to **Figure 50.** As far as tracks « Cymb/Toms », « Kick » and « Snare » are concerned, $\overline{x_{11}}$ is contrastive. Such a contrast can be achieved using the addition of elements (« Cymb/Toms »), a pattern change (« Snare »), or the silencing of the track (« Kick »). The « Dble Kick » track is uniform throughout the whole extract and therefore non-contrastive.

While the track « Guitar » is also uniform throughout the whole extract, the track « Guitar Harm » presents a notable feature. It is made from two instances of a downward *glissando* of harmonics, the first instance lasting nine beats and the second one lasting seven beats. A very simple way to describe this extract is therefore to consider as residual the length and speed difference between the two *glissandi*. The systemic part of the description will then feature two instances of the same downward *glissando*, leading to a non-contrastive system where $g=id$.

273 Copied from Pierre BOULEZ, *Messagesquisses pour 7 violoncelles (1976)*, Universal Edition No. 16678, Universal Edition, 1977, p. 13, rehearsal mark « b ». In M.I.A.'s case, the description is made using the cubic S&C model, and the accents are used as part of the Γ relation. In Pierre Boulez, the description is made using an iterative rule and the accents are used as part of the *f* relation. The fact remains that in both cases, accents are a musical dimension on which the morpho-syntagmatic systemic relations are based.

274 In which case chord sequences would not be pertinent in the context of « studio-based popular music ».

275 Gojira, « Planned Obsolescence », *L'Enfant Sauvage*, Roadrunner, 2012, 0'42-0'52. Transcription made by the author.

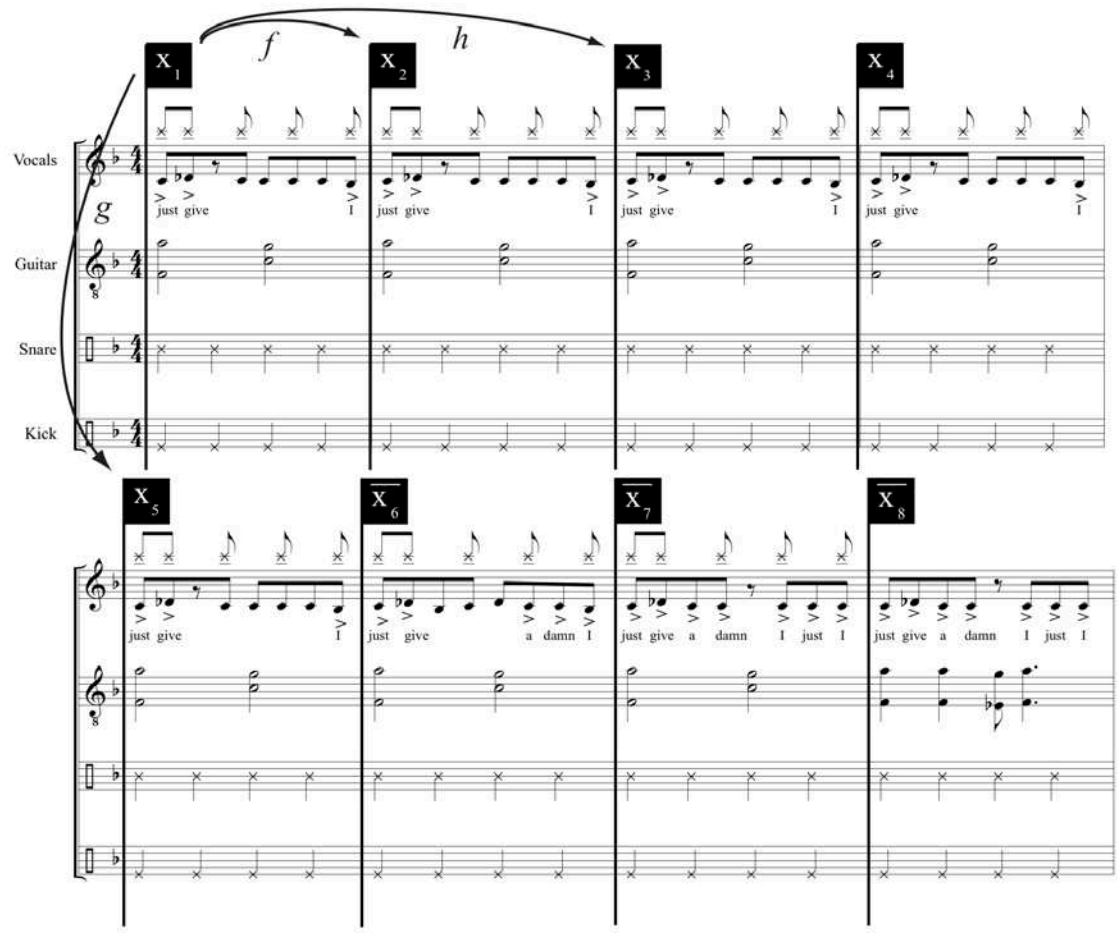

Figure 48. M.I.A's « Meds and Feds » without the residual part of the description. We observe that $\overline{X_6}$, $\overline{X_7}$ and $\overline{X_8}$ are contrastive.

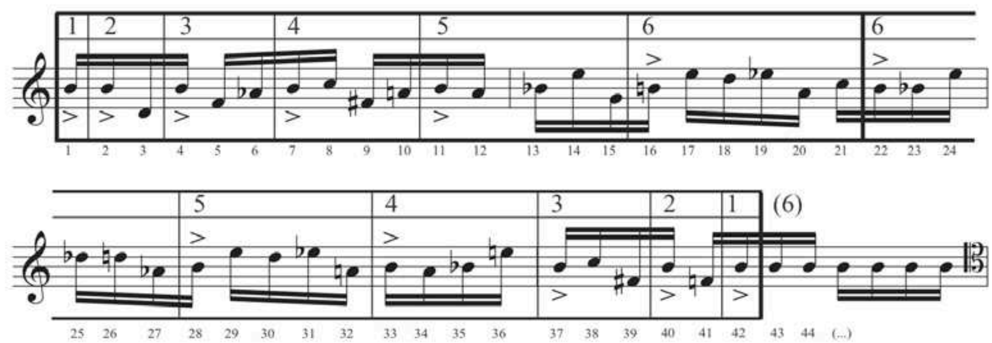

Figure 49. Description of an extract from Pierre Boulez' *Messagesquisse* also shows a systemic use of accents[276].

276 In both examples, accents are not the only systemic elements. In *Messagesquisse* for instance, a morphological unit always begins with a « B ». However, this doesn't invalidate the observation according to which there exist systems of relations in the context of which accents are used as a musical parameter.

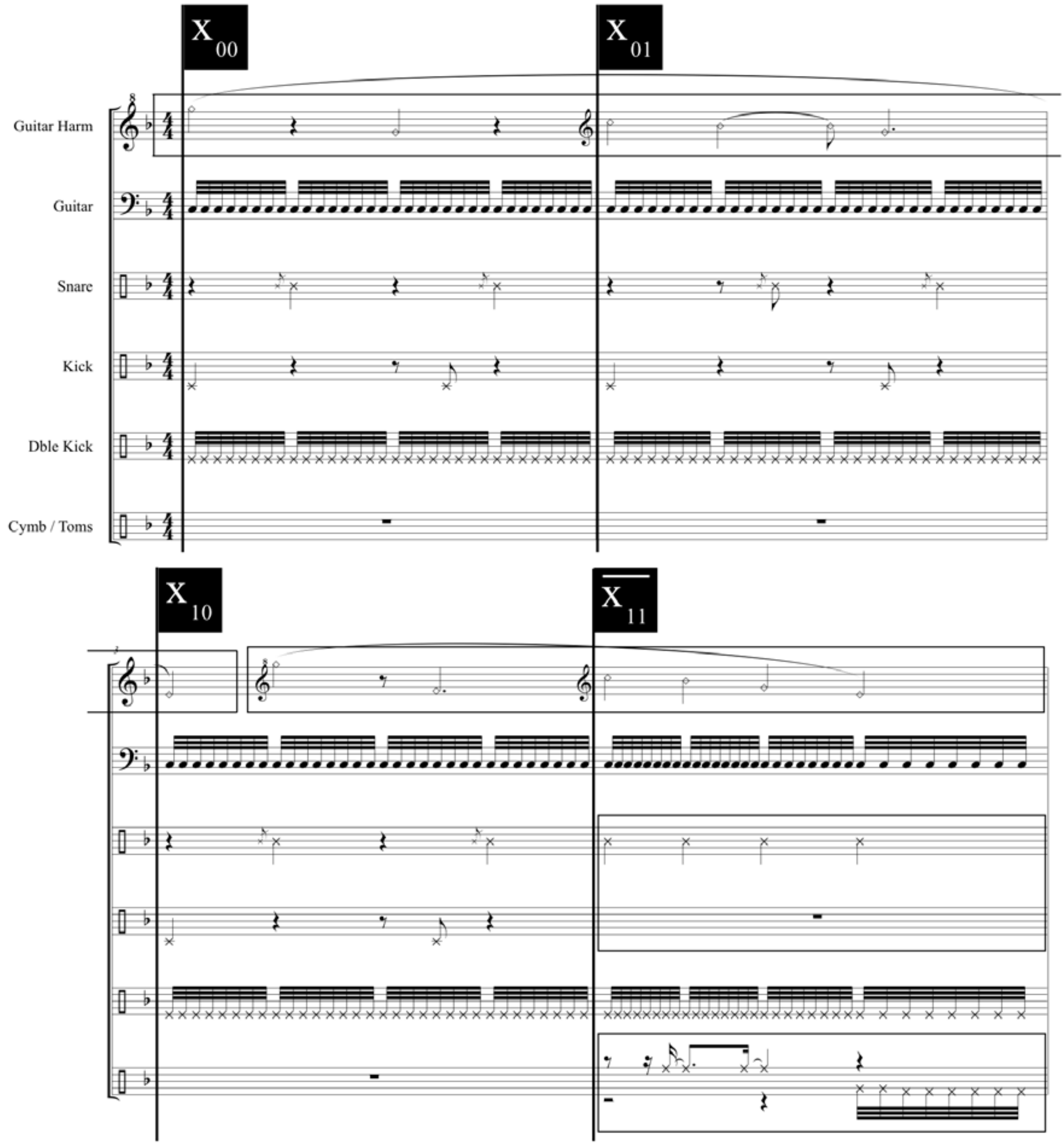

Figure 50. Transcription of Gojira's « Planned Obsolescence »[277].

277 The track called « Guitar Harm » is the result of a guitar technique that can be referred to as an harmonic *glissando*. While the heard fundamental note is displayed in « Guitar Track », the harmonics also provide recognizable pitch that are transcribed on the « Guitar Harm » track. The track called « Dble Kick» consists in a kick drum played very rapidly, which may be the result of a kick drum played with a dual pedal, or the use of two kick drums. The track called « Cymb / Toms » contains a combination of cymbal and tom-tom drum parts. For the tom-tom drum, see James BLADES and James HOLLAND, « Tom-tom », *Grove Music Online*, Oxford Music Online, Oxford University Press, http://www.oxfordmusiconline.com/subscriber/article/grove/music/28095 (accessed on August 7th, 2013).

This is an important conclusion we can draw from the observation of Gojira's « Planned Obsolescence »: the residual part of the description may not only consist in elements that can be added or subtracted from the systemic part[278], it may also consist in transformations of the original content, in this case a transformation in the length and speed of an observed pattern.

V.3.4. Adèle, « Skyfall ».

In this Subsection, we take advantage of a particular example in order to consider an adaptation the problem of « visual form » as introduced by Eugene Narmour[279]. This leads us to provide another illustration for the problem involving the compromise between accuracy and compacity, as illustrated on **Figure 42** from **Chapter IV, Section 6**.

Figure 51 represents the transcription of a semiotic unit from Adèle's « Skyfall » using a square S&C model[280]. In this perspective, the description of the « Piano », « Guitar » and « Bass » tracks doesn't result in particular problems. We focus on the « Lead » part, which appears to be a bit more complex. In his article about « rule-mapping », Eugene Narmour suggests the notion of « visual form », a schematic representation of the melodic profile. While we're not going to exactly borrow such a representation, we find that it possesses the considerable quality of addressing a « global » or « rough » melodic profile that mirrors certain aspects the music that's studied. This quality is even more pertinent to our work in regard to the fact that such a schematic representation may be considered as the result of the removal of a residual part[281].

We consider this principle in regard to « Skyfall »'s « Lead » part, and look for such schematic representations that would form a system. According to the MDL principle as seen in **Chapter III, Section 1**, and according to the definition of the square S&C model, we're looking for similarities between the first three morphological units, if possible including the fourth element. Reasoning in terms of « visual form », and as highlighted using rectangles on **Figure 51**, we identify three similar « forms » in $\boldsymbol{X}_{00}$, $\boldsymbol{X}_{01}$ and $\boldsymbol{X}_{10}$.

These forms can be described as the succession of an upward (« C3 » to « D3 ») and a downward movement (« D3 » to « C3 »). In the case of x_{11}, only the upward movement can be observed. It is followed by another upward movement rising to a « G3 ». **Figure 52, top,** singles out the « Lead » part.

278 As is the case with the first bar in M.I.A.'s extract of « Meds and Feds », or with the example shown in **Chapter III, Section 3.**
279 Eugene NARMOUR, *op. cit.*, 2000, p. 378.
280 ADÈLE, « Skyfall », *Skyfall*, XL / Sony Music Entertainment, 2012, 0'59-1'23. Transcription made by the author.
281 Residual part, as seen in **Chapter III, Section 3**.

An important problem concerning the systemic relations between such « visual form » is that their description is, at best, approximate. Stating for instance, as done above, that a movement « happens sooner and sooner » may not be satisfactory, though it possesses the undeniable advantage of being short and simple. This provides another illustration for the quandary according to which, as schematized on **Figure 42** from **Chapter IV, Section 6**, the more thorough the description, the less compact it is, and conversely, the looser the description, the more compact it is. This is a point we will devote particular attention to in the context of our planned PhD.

In **Figure 52, bottom,** we dim the residue leading to such a schematized description, therefore isolating the notes that support the « visual form »[282]. We focus on the « visual form » thus formed, or, which amounts to the same, on the notes underlying this « form ». Description of these notes can also be divided into a residual and a systemic part. For instance, if we consider the ascending movement in X_{00}, X_{01} and X_{10}, we can observe that it happens sooner and sooner. In this regard, unit X_{11} is contrastive. Similarly, if we consider the descending movement in X_{00}, X_{01} and X_{10}, we can observe that it happens slower and slower[283]. In this regard, unit X_{11} is not contrastive.

Figure 51. Transcription of a semiotic unit from Adèle's « Skyfall ».

282 It is important to point out that our focus on the notes that support the « visual form » isn't *a priori* related to a reflection on what would be the « important » or « support » notes. Deduction of such notes is, as usual, based on the MDL principle. The central question, as always, revolves about the simplest description we can find.

283 This approach indeed possesses common points with Narmour's « rule-mapping » as seen in Eugene NARMOUR, *op. cit.*, 2000. In the context of the present examples, the difference between our approach and Narmour's is the same as mentioned in **Chapter II, Section 2.** We consider the fourth element to be part of the system as a contrast, whereas Narmour's approach excludes it from the binding occasioned by rule-mapping.

Figure 52. Determination of « visual forms » in the « Lead » part from Adèle's « Skyfall ». Grayed parts are considered as residual.

V.3.5. Jedi Mind Tricks, « Raw feat. Randam Luck ».

In this Subsection, we describe a semiotic unit from a song that features an interesting behavior in terms of panoramic position of a particular source[284], which will lead us to conclude to a notable formal pattern.

The song we consider is « Raw feat. Randam Luck » by Philadephian collective Jedi Mind Tricks[285]. Transcription of the studied semiotic unit is given in **Figures 54 and 55**. While there are a number of tracks from this semiotic unit that can be efficiently described using different instances of the S&C model class, we will focus on the « Breaks » staff, whose panoramic position is transcribed on the « Pan » staff.

If we describe the ensemble of the semiotic unit using a hypercubic S&C, the « pan » behavior of the break staff in X_4, X_8 and X_{12} is remarkable or « abnormal », in the sense that such rapidly switching « pan » are seldom heard[286]. If we note as « 0 » the absence of elements on the « Breaks » staff, as « 1 » the presence of the pattern as observed in X_4[287], as « 2 » the presence of the same pattern as observed in X_{16}[288], and as « 3 » the presence of a different pattern, then the sixteen units can be written as $\{0,0,0,1,0,0,0,1,0,0,0,1,0,0,3,2\}$.

284 The « panoramic position » or « pan » of a source in the stereo sound image refers to its lateral position in regard to the loudspeakers. A source can be positioned on the Left, at the Center, on the Right, or at any position in between. The « pan » of a source is a fundamental notion in the context of « mixing ». For more on this subject, a comprehensive lecture is provided in William MOYLAN, *op. cit.*, 2007. In the current example, we find both panning being used as a contrast, and how it is used as a contrast, to be remarkable.

285 JEDI MIND TRICKS, « Raw, feat. Randam Luck », *Greatest Features*, Babygrande Records, 2009, 0'28-0'50. Transcription made by the author.

286 The « pan » of the « Breaks » staff switches from Left to Right on each eighth-note. No solid references can be found in regard to the assertion according to which this is an unusual behavior, since it is not possible to find annotations of « pan » behaviors over large music *corpora*. However, typical « pan » behaviors are written down in William MOYLAN, *op. cit.*, 2007, which are generally more continuous than rapidly switching.

287 With the « abnormal » panoramic behavior.

288 This time with a « normal » panoramic behavior.

We focus on units X_4, X_8, X_{12} and X_{16}, and consider the implications to which they're subject as formalized in **Chapter IV, Section 4**:

- X_4: X_4 is always the fourth unit of $\{X_1, X_2, X_3, \overline{X_4}\}$.
- X_8: redundancies between X_4 and X_8 eliminate the description of X_8 as being the fourth unit of $\{X_5, X_6, X_7, \overline{X_8}\}$. Both $\{X_2, X_4, X_6, \overline{X_8}\}$ and $\{X_3, X_4, X_7, \overline{X_8}\}$are acceptable. A slightly more obvious redundancy between X_2 and X_4 in the « Lead » track makes us consider X_8 as the fourth unit of $\{X_2, X_4, X_6, \overline{X_8}\}$[289].
- X_{12}: similarly to X_8's case, redundancies between X_4 and X_{12} eliminate the description of X_{12} as being the fourth unit of $\{X_9, X_{10}, X_{11}, \overline{X_{12}}\}$. Both $\{X_3, X_4, X_{11}, \overline{X_{12}}\}$ and $\{X_3, X_4, X_{11}, \overline{X_{12}}\}$ are acceptable. A slightly more obvious redundancy between X_2, X_4, X_{10} and X_{12} in the « Lead » track makes us consider X_{12} as the fourth unit of $\{X_3, X_4, X_{11}, \overline{X_{12}}\}$[290].
- X_{16}: important redundancies between the « Breaks » track in units X_4, X_8, X_{12} and X_{16} make us prefer considering X_{16} as $\{X_4, X_8, X_{12}, \overline{X_{16}}\}$'s fourth unit.

Using the notation mentioned above, we can write the four systems in regard to the « Breaks » part as:

- $\{X_1, X_2, X_3, \overline{X_4}\} = \{0, 0, 0, 1\}$.
- $\{X_2, X_4, X_6, X_8\} = \{0, 1, 0, 1\}$.
- $\{X_2, X_4, X_{10}, X_{12}\} = \{0, 1, 0, 1\}$.
- $\{X_4, X_8, X_{12}, \overline{X_{16}}\} = \{1, 1, 1, 2\}$.

The same pattern from the « Breaks » track is therefore presented four times as the fourth element of a system. The first time, the element is contrastive. The second and third times, the element is not contrastive. The fourth time, whereas an identical presentation of the pattern would lead to a uniform and non-contrastive $\{X_4, X_8, X_{12}, X_{16}\} = \{1, 1, 1, 1\}$, a γ relation is applied to X_{16}, which, in regards to the panoramic behavior of the unit, is the inverse of the first γ relation, the one that's applied to $\overline{X_4}$. The « pan » behavior, if one may say so, is « back to normal », so as to make $\overline{X_{16}}$ contrastive.

A schematized summary can be found on **Figure 53.** It may be interesting to describe a number of other examples in the purpose of checking whether such a « double inversion » of a particular musical parameter may be a standard scheme, and if so, whether there may be other standard schemes.

289 The reasoning stands with either of these two systems.

290 The reasoning stands using either $\{X_9, X_{10}, X_{11}, \overline{X_{12}}\}$ or $\{X_2, X_4, X_{10}, \overline{X_{12}}\}$.

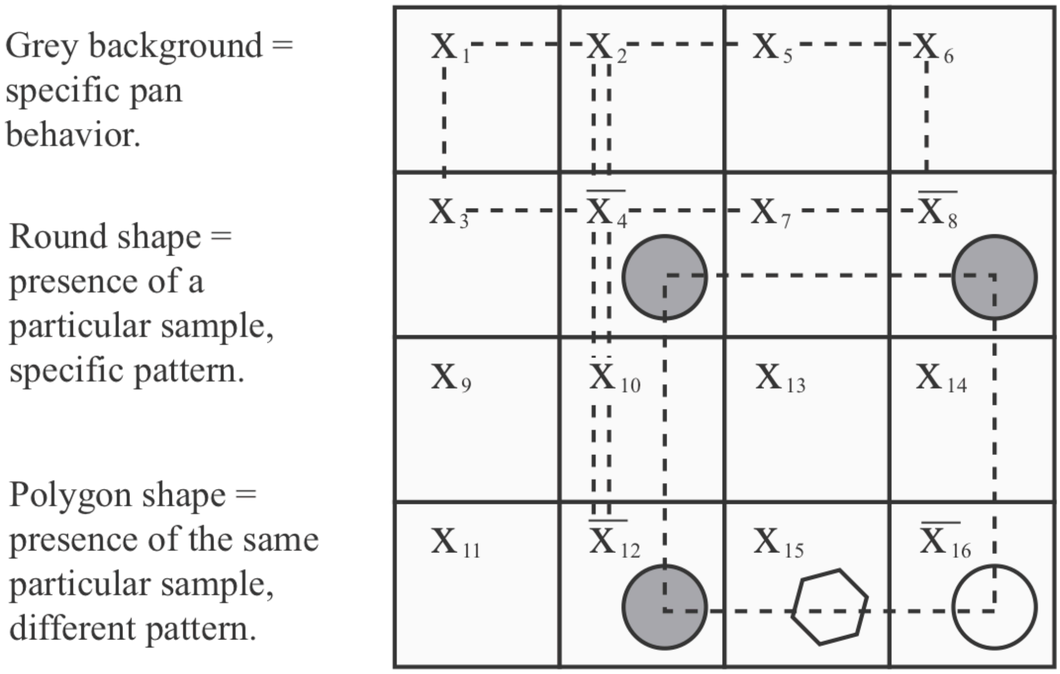

Figure 53. The panoramic positions of the elements from the « Breaks » track in « Raw feat. Randam Luck » can be described using the system $\left\{X_4, X_8, X_{12}, \overline{X_{16}}\right\}$, where the contrastive relation is actually the inverse of the contrastive relations in the systems from which $\overline{X_4}$, $\overline{X_8}$ and $\overline{X_{12}}$ are themselves the contrast.

Figure 54. « Raw feat. Randam Luck », morphological units 1 to 8[291].

291 The « Breaks » and « Pan » tracks are detailed above. For the respective definitions of « Kick », « Snare », « Hi-Hat » and « Pads », see **Chapter IV, Section 3**.

Figure 55. « Raw feat. Randam Luck », morphological units 9 to 16.

V.3.6. Immortal Technique, « Harlem Streets ».

In this Subsection, we illustrate the use of the square S&C model in the characterization of the relationships between an original melody from the romantic era and its reprise in a rap song. In the song « Harlem Streets »[292], the American-Porto Rican rapper known under the alias « Immortal Technique » uses a melody he borrows from Johannes Brahms' third symphony, third movement[293]. This melody is highlighted on **Figure 56.** Described as a square S&C model, we have $f = id$. and the contrastive relation γ, amongst other properties, consists in a change of the melody in the context of a rough conservation of the melodic profile.

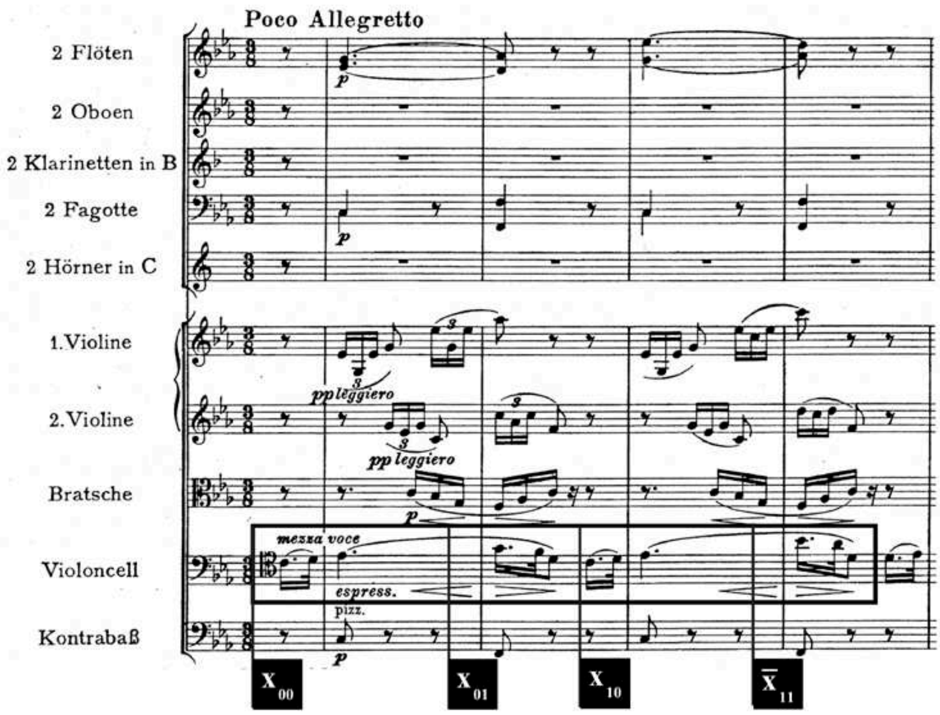

Figure 56. Johannes Brahms' « Sinfonie Nr. 3 », 3rd movement, bars 1 to 4.

292 Immortal Technique, « Harlem Streets », *Revolutionary vol. 2*, Viper Records, 2003, 0'22-0'34. Transcription made by the author.
293 Johannes BRAHMS, « Sinfonie Nr. 3 in F-Dur », op. 90, 3rd movement, « Poco Allegretto », 1883, bars 1-4. Edition: Hans GÁL, *Johannes Brahms: Sämtliche Werke, Band 3*, Breitkopf & Härtel, 1926–27, p. 38.

Figure 57 shows a transcription of an excerpt from Immortal Technique's « Harlem Streets » instrumental part[294]. There are numerous differences between the two music pieces, of which we won't make a list, leaving this operation to the reader. Instead, we will single out one important difference.

While in the case of the original melody, $g=id.$, in the case of Immortal Technique's unit, g includes a downward transposition of one octave. The reprise of Brahm's melody is therefore accompanied with a change in the systemic relations themselves.

Such an example of relationship study between a musical borrowing and the original piece may provide for an interesting field of investigation in other cases[295].

V.3.7. Depeche Mode, « World in my Eyes ».

In this Subsection, we illustrate how a contrast from a square S&C model can take advantage on the music's modal content.

We describe a semiotic unit from Depeche Mode's « World in my Eyes »[296] using the square S&C model, the transcription of which can be found in **Figure 58**. In x_{00}, x_{01} and x_{10}, only three notes are used: « D flat », « E flat » and « G flat ». During $\overline{x_{11}}$, the « break » track uses two additional notes, « A flat » and « B flat ». This results into two notable properties:

- Implications projected on « A flat » from x_{00}, x_{01} and x_{10} do not presuppose the presence of these two additional notes. This results into a « modal contrast » brought by the « break » track during $\overline{x_{11}}$.
- The ensemble of $\overline{x_{11}}$'s notes, « D flat », « E flat », « G flat », « A flat » and « B flat » form a complete pentatonic scale. As a result, the presence of the two additional notes in $\overline{x_{11}}$ resonate well with $\overline{x_{11}}$ being the element making possible the formation of a « complete musical idea » as mentioned in **Chapter I, Section 3** and **Chapter II, Section 2**[297].

Such a « complete musical idea », unlike Schoenberg's, can be expressed without a cadence. This may open an interesting field of investigations, in relation to the very « nature » of a « complete musical idea »[298].

294 The lead vocal part, or « flow » is not transcribed. For the definition of « flow », see David TOOP & al., « Rap », *Grove Music Online*, Oxford Music Online, Oxford University Press, http://www.oxfordmusiconline.com/subscriber/ article/ grove/music/A2225387 (accessed on August 11th, 2013).

295 In Rap music for instance, sampling, a form of musical borrowing, is at the core of the creative process, see David TOOP & al., *op. cit*. Musical borrowing is long-standing practice in any style of music, see for instance Olufunmilayo B. AREWA, « From J.C. Bach to Hip Hop: Musical Borrowing, Copyright and Cultural Context », *North Carolina Law Review*, LXXXIV/2 (2006), p. 547-645.

296 DEPECHE MODE, « World in my Eyes », *Violator*, Sire, 1990, 0'36-0'51.Transcription made by the author.

297 Following this train of thought, the addition of the two notes resulting in a complete pentatonic scale may be compared to a « cadential idea » as defined by Schoenberg and Caplin and as seen in **Chapter I, Section 3** and **Chapter II, Section 2**.

298 In the present case, « completeness » comes in the form of a « complete » pentatonic scale. A possible formulation of the issue might concern other possible and/or viable forms of « completeness ».

Figure 57. An excerpt from Immortal Technique's « Harlem Streets ».

Figure 58. The contrast in Depeche Mode's « World in my Eyes »[299] is based on the music's modal content.

299 In the context of this score, « HH » stands for « Hi-Hat », « Perc » for « Percussions », « Key » for « Keyboard », and « Lead » for « Lead Vocals ». See **Chapter IV, Section 3** for the respective definitions of « Kick », « Snare », and « Hi-Hat ».

SUMMARY.

As a final step to the present work, we first recapitulate the various points covered by this work and then we highlight a number of conclusions that emerge from our investigations

The ensemble of time scales referred to as « melodic and rhythmic grouping » by Bob Snyder[300] corresponds to the level of « form » as defined by Arnold Schoenberg and William Caplin in the context of the *Formenlehre*[301]. The upper limit for such a level of « form » has been specified as a « semiotic unit » in our previous work, and corresponds to what is referred to as « period » or « sentences » in the field of *Formenlehre*[302].

« Form », be it the totality of the semiotic unit or part of it, can be described as a system of morphological units linked together by relations, part of which can be shown to be implication rules as defined by Eugene Narmour. While Narmour's rules are based by hypothesis on iteration, the S&C model is based by hypothesis on a system of analogy[303]. In the present work, we illustrate the fact that f and g are implication relations, and we derive from this hypothesis the square S&C model for the description of form, which we sum up as $\{x_{00}, f, g, \gamma\}$. In this expression, f and g are the implication relations, and γ represents the difference between the implication as realized and music as observed[304].

Music is data. As stipulated by the principle of Minimum Length Description, knowledge about data can be acquired by compressing it, i.e. by expressing it in a shorter or simpler way than its literal description[305]. Such compression can be achieved by exploiting redundancies in data. In the case of the square S&C model, this means minimizing the expression of f, g, and γ. This provides an important methodological guideline in the perspective of describing music with the S&C model, as well as a clear discovery criterion[306].

According to the MDL principle, a piece of music should be ideally learnt about when expressed in the simplest possible way. However, two obstacles have to be considered. First, Kolmogorov's theory of complexity stipulates that given any data, it is never possible to find its most compact expression. Then, considering the simplest expression for any piece of music would result in as many descriptions of the musical form as there are music pieces. This justifies the use of a limited number of models. A compromise must be reached between the acquired knowledge and the number of models[307].

300 Or « morpho-syntagmatic level » in our previous work.
301 But not the level of « form » as defined by Bob Snyder, which corresponds to our level of the semiotic structure.
302 Corresponding content and references can be found in **Chapter I**.
303 Such a hypothesis can be summed as follows: « given four elements, the first three elements project an implication onto the fourth one. The implication is realized when element 4 is to element 3 what element 2 is to element 1, and when element 4 is to element 2 what element 3 is to element 1. »
304 Corresponding content and references can be found in **Chapter II**.
305 In the context of the Minimum Length Description, « shorter » and « simpler » are equivalent.
306 Of which many music analysis methods have been said to lack. Corresponding content and references for this paragraph can be found in **Chapter III**.
307 Corresponding content and references can be also found in **Chapter III**.

The square S&C model is at the origin of the S&C class of models. While the present work provides only a partial and maybe temporary definition of the S&C class of models, it points towards a number of important characteristics for it. In particular, we stipulate that all instances of the class are derived from the initial hypothesis of analogy, and are therefore extensions of the square S&C model, which we can generically sum up as $\{x_1, F, \Gamma\}$[308]. Amongst other models, we define the cubic and hypercubic forms of the S&C model class, which can be expressed as compositions of the square S&C model. Definition of such models results into the acknowledgment of potentially conflicting implications. This problem is shown as being addressable by the Minimum Length Description principle[309].

A fundamental hypothesis behind our defining of the S&C class of models is that it may achieve compromise between the acquired knowledge and the number of models, at least as far as some music genres are concerned[310]. While this may prove difficult to formally demonstrate, we can at least show that the S&C class of models proceeds from reasonable assumptions. The main assumption behind the S&C class lies in the hypothesis according to which $\{x_1, F, \Gamma\}$ is more compact[311] than the music's literal description.

Such an hypothesis is shown to be justified by the fact both F and Γ may be assumed to be more compact than the music's literal description as soon as the music section has been grouped using primitive grouping in the *Gestalt* sense.

It is further justified by the assumption according to which Γ, by expressing « what is » in relation to « what could have been », provides better knowledge of the music. An interpretation of the term « contrast » is therefore given, in which the first three units would project an expectation onto the potentially contrastive unit, which in turn would provide a « calibration » for the other units[312].

Besides considerations of music pieces from the Viennese classical era, further potential applications of the S&C model class are provided by the study of several examples of what we define as « studio-based popular music ». Such applications may include gimmick characterizations in « hit » songs, determinant of form definition in electronic music, and perspectives concerning the analytical study of musical borrowings[313].

308 In this representation, x_1 is the system's first element, F refers to the ensemble of implication relations, and Γ to the ensemble of differences between the projected implications and the observed music.
309 Corresponding content and references can be found in **Chapter IV**.
310 During the course of this work, we've been focusing on the Viennese classical period and on « studio-based popular music » as defined in **Chapter V**.
311 Or smaller, or simpler, or providing knowledge about the observed data. All these formulations are equivalent.
312 Corresponding content and references can also be found in **Chapter IV**.
313 Corresponding content and references can be found in **Chapter V**.

CONCLUSIONS.

As a result of the investigations reported in the present work, we point towards the following conclusions.

A fundamental hypothesis behind this work lies in the conviction according to which rationalization of music analysis is a potentially productive domain, be it in the formulation of the discovery criteria on which music analysis relies[314], or in the perspective of acquiring methods making possible a selection between concurrent descriptions[315]. However, this is a point of view that leads to an essentially multidisciplinary reflection. In this regard, we hope that the present work will be useful in drawing bridges between the formalist, logic aspects of the S&C model[316] and its musicological side.

We feel that the introduction of the S&C model, as a description method that can be indifferently used in the case of music from the Viennese classical era or in the case of recent popular music, suggests that the « bridging [of] the gap »[317] between so-called « art » and « popular » music is a realistic perspective.

Of course, a substantial amount of work remains, which makes the topic very challenging. In particular, the analysis of more music extracts should be performed so that a statistical study can be initiated. Also, a further extension of the stylistic scope would be welcome. And while bridges with the field of musical expectation have been made, other proper connections with particular domains should be established, such as with the generative theory of music[318] or the neo-riemannian transformational theory[319].

314 As mentioned in **Chapter III, Section 2** and in Nicolas RUWET and Mark EVERIST, *op. cit.*, 1987, p. 13.
315 Which, as seen in **Chapter III, Section 1**, the MDL principle is liable to provide.
316 In particular to issues related to logical implications and to the Minimum Description Length principle.
317 The expression is voluntarily borrowed from Richard MIDDLETON, « Popular Music Analysis and Musicology: bridging the gap », *op. cit.*, 1993.
318 See Fred LERDAHL and Ray JACKENDOFF, *A Generative Theory of Tonal Music*, M.I.T. Press, 1983.
319 David LEWIN, « A Formal Theory of Generalized Tonal Functions », *Journal of Music Theory*, XXVI (1982), p. 23-60.

APPENDIX: ANALYSIS DETAILS.

Appendix to Chapter IV, Section 3. Analyzing conflicting implications, case of the cubic S&C model.

Figure 30 from the main text body illustrates conflicting implications projected on the eighth unit of a cubic system. The top ensemble staff shows the original extract. The three other ensemble staves respectively show units and implications for systems $\{x_5, x_6, x_7, x_8\}$, $\{x_2, x_4, x_6, x_8\}$ and $\{x_3, x_4, x_7, x_8\}$. Implications are drawn in grey. The extract is made from six parts. From bottom to top:

- « Kick » track: three conflicting implications can be observed. The original extract realizes one of the implications, with system $\{x_2, x_4, x_6, x_8\}$ not being contrastive.
- « Snare » track: two conflicting implications can be observed. The original extract denies all implications, which leads all three systems to be contrastive.
- « Rim » track: two conflicting implications can be observed. The original extract realizes the implication for one system out of three[320].
- « Hi-hat » track: all implications converge. The original extract realizes the implication.
- « Key » track: in the context of this melodic part, only one implication can be observed[321]. It corresponds to system $\{x_5, x_6, x_7, x_8\}$. According to **Chapter III, Section 3**, we prefer to consider as residual the absence of a « C » at the beginning of the system.
- « Hi Pad » track: even though the part is very sparse, converging implications can be observed. The original extract realizes the implication.

Several parts exhibit conflicting implications: the « Kick », « Snare », and « Rim » part. Conflicting implications can be considered as different explanations of a given phenomenon, namely the projection of implications on x_8. As seen in **Chapter II, Section 1**, « if several explanations [...] of a given phenomenon [...] exist, then we should pick the simplest [...] one »[322].

320 In accordance to **Chapter III, Section 3**, the « rim » part can also be considered as non-systemic and entirely residual.

321 In the case of $\{x_2, x_4, x_6, x_8\}$ and $\{x_3, x_4, x_7, x_8\}$, relations f *and* g *are* too complicated to be expressed.

322 Ming LI and Paul VITÁNYI, *op. cit.*, 2008, as cited by Peter D. GRÜNWALD, *op. cit.*, 1998, p. ix. The complete sentence is « if several explanations (programs) of a given phenomenon (data) exist, then we should pick the simplest (shortest) one ».

In the case of the « Key » part, this principle of simplicity has been already applied. Observing that f and g are very complicated to describe in the case of two of the three systems that include x_8 as a potentially contrastive element, we only retain $\{x_5, x_6, x_7, x_8\}$ as a viable system, therefore having to only deal with one implication. Since the original « Key » part is contrastive in regard to this system, we will retain $\{x_5, x_6, x_7, \overline{x_8}\}$ as a preferred description.

In the case of the « Kick » part, where three conflicting implications can be observed, system $\{x_2, x_4, x_6, x_8\}$ is both the simplest (all four units identical) and the only one to be non-contrastive. Our choice for a preferred description falls on this system. In the case of the « Snare » part, all three systems are contrastive. However, system $\{x_2, x_4, x_6, x_8\}$ is the simplest, with all four units being non-contrastive. In the case of the « Rim » part, system $\{x_3, x_4, x_7, x_8\}$ is both very simple (all four units are identical and silent) and non-contrastive.

Appendix to Chapter IV, Section 4. Analyzing conflicting implications, case of the hypercubic S&C model.

We consider the tracks « S.1 », « S.2 » and « S.A. » from the example shown on **Figure 32** from the main text body. We start with unit 8, which is subject to three potentially conflicting implications:

- System $\{x_2, x_4, x_6, x_8\}$. Implications are simple (« A, B, A, ? »). Unit x_8 should be identical to x_4, which it is. The system is non-contrastive.
- System $\{x_3, x_4, x_7, x_8\}$. Implications are simple (« A, B, A, ? »). Unit x_8 should also be identical to x_4, which it is. The system is non-contrastive.
- System $\{x_5, x_6, x_7, x_8\}$. Implications are difficult to formulate. This makes $\{x_5, x_6, x_7, x_8\}$ a poor candidate. However, we can tell that none of the tracks should be silent, which makes the actual x_8 a denial.

We therefore prefer implications that correspond to the systems $\{x_2, x_4, x_6, x_8\}$ and $\{x_3, x_4, x_7, x_8\}$, which converge and are non-contrastive. Further adjudication is not specified in the present work[323]. We continue with unit 12, which is subject to three potentially conflicting implications:

- System $\{x_2, x_4, x_{10}, x_{12}\}$. Implications are simple (« A, B, A, ? »). Unit x_{12} should be identical to x_4, which it is. The system is non-contrastive.
- System $\{x_3, x_4, x_{11}, x_{12}\}$. Implications are simple (« A, B, A, ? »). Unit x_{12} should be identical to x_4, which it is. The system is non-contrastive.
- System $\{x_9, x_{10}, x_{11}, x_{12}\}$. Implications are difficult to formulate.

We therefore prefer implications that correspond to the systems $\{x_2, x_4, x_{10}, x_{12}\}$ and $\{x_3, x_4, x_{11}, x_{12}\}$, which converge and are non-contrastive.

323 It might be considered using the actual simplicity of each morphological unit, but that's a problem we reserve for our planned PhD.

We go on with unit 14, which is subject to three potentially conflicting implications:

- System $\{X_2, X_6, X_{10}, X_{14}\}$. Implications are simple (« A, A, A, ? »). Unit X_{14} should be identical to X_2, which it is. The system is non-contrastive.
- System $\{X_5, X_6, X_{13}, X_{14}\}$. Implications are simple (« A, B, A, ? »). Unit X_{14} should be identical to X_6 (and therefore to X_2), which it is. The system is non-contrastive.
- System $\{X_9, X_{10}, X_{13}, X_{14}\}$. Implications are also of the (« A, B, A, ? » type. Unit X_{14} should be identical to X_{10} (and to X_2), which it is. The system is non-contrastive.

The three implications converge and don't conflict. However, one can notice that should we select a particular system to describe implications on X_{14}, $\{X_2, X_6, X_{10}, X_{14}\}$ seems to be a good candidate, as it tends to be even simpler than the others.

We proceed with unit 15, which is also subject to three potentially conflicting implications:

- System $\{X_3, X_7, X_{11}, X_{15}\}$. Implications are simple (« A, A, A, ? »), X_{15} should be identical to X_3, yet it is a bit different, with three extra notes. The system is contrastive.
- System $\{X_5, X_7, X_{13}, X_{15}\}$. Implications are of the (« A, B, A, ? ») type, X_{15} should be identical to X_7 (and therefore to X_3). The system is contrastive.
- System $\{X_9, X_{11}, X_{13}, X_{15}\}$. Implications are of the (« A, B, A, ? ») type, X_{15} should be identical to X_{11} (and therefore to X_3). The system is contrastive.

The three implications converge, and none of them is realized. Should we select a particular system to describe the implications projected on X_{15}, $\{X_3, X_7, X_{11}, X_{15}\}$, would tend as being the simplest.

As for unit 16, it is subject to six potentially conflicting implications:

- System $\{X_4, X_8, X_{12}, X_{16}\}$. Implications are simple (« A, A, A, ? »), X_{16} should be identical to X_4, yet it's silent. The system is contrastive.
- System $\{X_6, X_8, X_{14}, X_{16}\}$. Implications are of the (« A, B, A, ? ») type, X_{16} should be identical to X_8 (and therefore to X_4), yet it's silent. The system is contrastive.
- System $\{X_7, X_8, X_{15}, X_{16}\}$. Implications are slightly more complex. Unit X_{16} should be a variant of X_8 (and to X_4), yet it's silent. The system is contrastive.
- System $\{X_{10}, X_{12}, X_{14}, X_{16}\}$. Implications are of the (« A, B, A, ? ») type, X_{16} should be identical to X_{12} (and therefore to X_4), yet it's silent. The system is contrastive.

- System $\{X_{11}, X_{12}, X_{15}, X_{16}\}$. Implications are slightly more complex. Unit X_{16} should be a variant of X_{12} (and therefore to X_4), yet it's silent. The system is contrastive.
- System $\{X_{13}, X_{14}, X_{15}, X_{16}\}$. Implications are difficult to specify. However, X_{16} shouldn't be silent. The system is contrastive.

Three of these implications converge towards X_{16} being identical to X_4. Two converge towards X_{16} being similar to X_4. A last implication is difficult to specify, but could be described as « expect at least something that's not silent ». All systems are contrastive, and all implications are denied. Should we select a particular system to describe the implications projected on X_{16}, our choice would fall on $\{X_4, X_8, X_{12}, X_{16}\}$, which is the simplest.

Appendix to Chapter IV, Section 5. Expression of $\overline{X_5}$ in relation to X_1 through $\overline{X_4}$.

Let's focus on the relationships between morphological unit $\overline{X_5}$ and X_1 through $\overline{X_4}$[324]. We proceed from top to bottom:

- Track « Vocals »: $\overline{X_5}$'s content is easily derived from X_1 through $\overline{X_4}$'s. It is simply silenced.
- Track « Scratch »[325]: $\overline{X_5}$'s content is also easily derived from X_1 through $\overline{X_4}$'s, since it is also silenced.
- Track « Guitar »: the simplest way to describe $\overline{X_5}$'s content is to consider it as a reversal of any of the carrier units' content, along with slight rhythm modifications[326].
- Track « Bass »: the easiest way to describe $\overline{X_5}$'s content in regard to X_1 through $\overline{X_4}$'s is to reverse any of the carrier unit's content, and change the first note to a « D »[327].
- Track « Crash »[328]: $\overline{X_5}$'s content is easily described in regard to either X_1, X_2, X_3, or $\overline{X_4}$, with the addition of a dotted eighth-note at the end of the second bar.
- Track « Hi-Hat »[329]: content of this track is identical in X_1 through $\overline{X_4}$. While content of $\overline{X_5}$'s first bar is identical to all other morphological units from the semiotic unit, a new, lighter pattern is introduced during the second bar of $\overline{X_5}$.

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324 This will be done while keeping in mind that our purpose is always to find the shortest/simplest formulation of given data, in this particular case of $\overline{X_5}$.

325 See Ian PEEL, « Scratching », *Grove Music Online, op. cit.*

326 The aspect of the note's attacks in $\overline{X_5}$'s guitar part suggests that it is actually the result of an actual reversal using studio processing capabilities.

327 The aspect of the attacks of notes 2, 4 and 4 from $\overline{X_5}$'s bass part suggests an actual reversal using studio processing capabilities. Only note 1 doesn't appear to have been reversed.

328 « Crash » stands for « crash cymbal », see GROVE MUSIC ONLINE, « Crash Cymbal », *Grove Music Online*, Oxford Music Online, Oxford University Press, http://www.oxfordmusiconline.com/subscriber/article/grove/music/J105300 (accessed on July 24th, 2013).

329 GROVE MUSIC ONLINE, « Hi-hat », *Grove Music Online*, *op.cit.*

- Track « Tuned snare »[330]: the track is silenced during $\overline{X_5}$, which makes it easily describable in regard to any of the other morphological units in the semiotic unit.
- Track « Snare »: the first bar is the same in $\overline{X_5}$ as it is in X_1 through $\overline{X_4}$. A new pattern is introduced in bar 2, which contains common points with the other morphological units.
- Track « Kick »: $\overline{X_5}$'s content can easily be derived from X_1 through $\overline{X_4}$, by simple filtering down of some elements.

Observation of the relationships between $\overline{X_5}$ and the other morphological units shows that $\overline{X_5}$ can indeed be considered as part of the semiotic unit shown on **Figure 38** from the main text body.

330 « Snare » stands for « snare drum », see GROVE MUSIC ONLINE, « Snare Drum », *Grove Music Online*, *op. cit.* We call « tuned snare » a snare drum from which a pitch can be clearly heard.

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